TEMPERATURE AND DENSITY STRUCTURE OF WATER ALONG THE CALIFORNIA COAST

by

Richard Warren Holly

UNITED STATES NAVAL POSTGRADUATE SCHOOL

THESIS

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December 1968

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ABSTRACT

A synoptic analysis of the temperature field off the California coast for the surface, 10-meter and 100-meter level is provided for the years 1958-1959. Data used are from CCOFI cruises.

These analyses are shown to be adequate for detecting probable upwelling areas. The areas of persistent upwelling are at 29 N, 31 N and 33 N adjacent to the California coast. There appears to be a preference for a steep gradient of the sea floor in these areas. The onset and decay of upwelling appears to depend on latitudinal position of the 11 C isotherm at 100 meters.

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ACKNOWLEDGEMENTS

The author wishes to express his appreciation for the guidance and assistance given by Professor Glenn H. Jung of the Naval Postgraduate School. Appreciation is also expressed to Dr. Taivo Laevastu, Lcdr. G. M. Griswold, and other personnel of the Naval Fleet Numerical Weather Central for their cooperation during the preparation of this paper.

For my wife, Chris, I reserve a most sincere thank you. Without her help the timely completion of this project would not have been possible.

I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

It is well established that seasonal upwelling takes place along the California coast (Sverdrup, 1942). The primary purpose of this study is to determine if a synoptic analysis of the temperature field can detect probable upwelling areas; and to verify these areas by the use of temperature versus salinity plots. Additional objectives of this study are to provide a small-scale temperature analysis of the upper waters off the California coast at the surface, 10-meter and 100-meter levels and to display any variability in these patterns.

Averaged synoptic sections of temperature have been constructed which show its seasonal variation in the horizontal and at selected levels of the surface, 10 meters, and 100 meters. These sections are used to show probable upwelling areas as well as small-scale advective influences of upper water masses.

The data were obtained from the Oceanic Observations of the Pacific (1958-1959) and are primarily composed of information gathered during cruises carried out jointly as California Cooperative Oceanic Fisheries Investigations (CCOFI). All data used were taken by Nansen casts and temperatures from non-scientific sources such as merchant ships or U.S. Navy operating forces were eliminated in hopes of eliminating erroneous readings.

Wolff (1967) and Saur (1963) estimate that sea water temperatures obtained from non-scientific sources may have an overall error of $\pm$ 1.1 degree Centigrade. Values of temperature were obtained by averaging all CCOFI observations over one-degree Marsden Squares for each month of the year.

Because of the distribution of available data, the area selected for study extends between 27-38 N and 114-126 W. The monthly averages of temperature were computed using the SCM COGITO 2405R digital computer.

There are inherent limitations in using averaged data to describe the fluctuations in temperature. These limitations involve distribution of data density in space and in time.

If a space average is to be representative, it must be composed of a reasonable number of observations, well distributed over the area. In the distribution of data in this study, this criterion was not always satisfied, and in some cases data points consist of a single sounding.

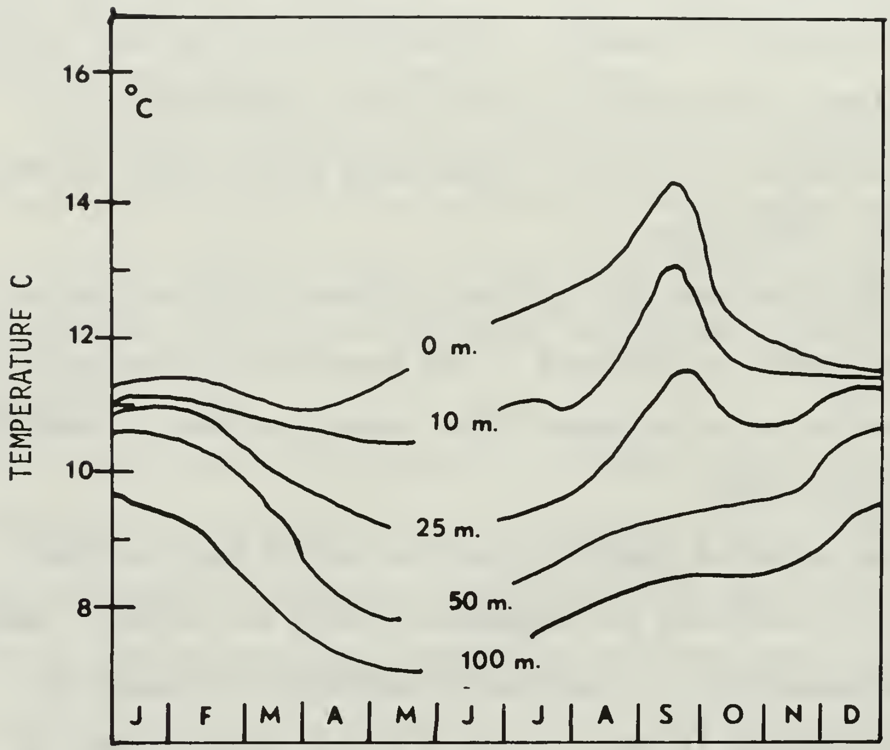
It is assumed that soundings are evenly spaced in time throughout the month. In general this is not the case since soundings were closely spaced in time over a period of a few days during the month. If the averaged quantity obtained was from data far from the monthly average due to a rare oceanic condition, then the results would not, probably, be representative of average conditions for that season.

B. SUMMARY OF PREVIOUS WORK

The description and explanation of the temperature structure in the upper waters off the California coast has been the subject of many oceanographic studies. Among the most notable was that by Skogsberg (1936) in which he describes the annual variation in temperature at Monterey Bay. He assumed that variation of temperature at subsurface depths depended upon four factors: (1) variation of the amount of heat that is directly absorbed at different depths; (2) the effect of heat conduction; (3) the variation in the currents related to lateral displacement of water masses; and (4) the effect of vertical motion. Skogsberg divided the year into three periods: the period of the Davidson Current, lasting from the middle of November to the middle of February; the period of upwelling between the middle of February and the end of July; and the oceanic period from the end of July to the middle of November. The period of the Davidson Current is characterized by relatively high and uniform temperature, and appears in the annual variation of temperature as warm water at subsurface depth. (See Figure 1.)

At the end of February the California Current again reaches to the coast and, under the influence of the prevailing northwesterly winds, an overturning of the upper layer takes place that is generally described as upwelling.

During the period of upwelling, vertical motion near the coast brings water of relatively low temperature toward the surface. Consequently, the temperature at given depths decreases when upwelling begins. This decrease is shown in Fig. 1 by the downward trend of the temperature at 25, 50, and 100 meters, at which depth the minimum temperature is reached at the end of May. The much higher temperature at the surface, as compared to that at 25 meters, shows that a thin surface layer is subject to heating by radiation; from the variation of temperature at 10 meters, which is shown by a thin line, it appears that the effect of heating is limited to the upper 10 meters. Toward the end of August, a sharp rise in temperature takes place both at the surface and at subsurface depths indicating the end of the upwelling period.



Temperature variability in Monterey Bay
(Skogsberg, 1936)

Figure 1

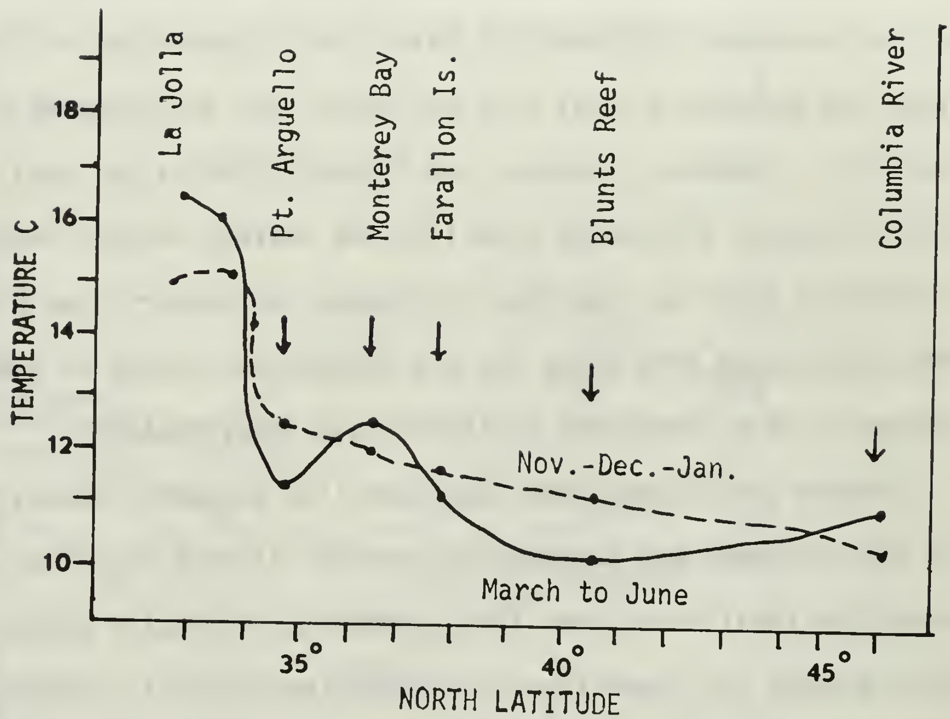
McEwen (1934) used serial temperatures to investigate the rate of upwelling off the coast of southern California. He found it to be a slow process showing the rate of upwelling to be on an average of 20 meters a month.

According to Sverdrup and Fleming (1941), the upwelling occurs only in the upper 200 meters of water, while deeper water flowing along the California coast does not enter into the dynamics of upwelling. Sverdrup, Johnson, and Fleming (1942) also concluded that in regions of intense upwelling the average surface temperature is lower in March to June than in November to January (see Fig. 2). They also stated that there was one conspicuous center of upwelling located at 35 N within the limits of this investigation.

Johnson (1939) concluded that upwelling gradually ceases toward the end of summer and patterns of currents flowing away from and toward the coast break down into a number of irregular eddies. This would account for temperature and densities typically associated with coastal waters being moved seaward and oceanic waters moving toward the coast. Studies by Schwartize (1963) and Reid (1965) confirm Johnson's findings.

Reid, Roden, and Wyllie (1958) present an excellent account of the progression of upwelling along the California coast. They show that upwelling first occurs off Baja California, in April and May, off southern and central California in May and June, and off northern California in June and July.

Lynn (1967) provided an excellent presentation of the variability of the temperature and density structure in the California current. Using CCOFI data records for 1950-1962 and regression analysis,



Surface Temperature Along the California Coast
(Sverdrup et al., 1942)

Figure 2

harmonic curves are fitted to each coastal station record. The harmonic curves and descriptive statistics provide a description of seasonal variation of temperature and density at the 10-meter level. Lynn's results agree in general with the preceding investigations of Sverdrup (1942) and Reid (1960).

II. DATA TREATMENT AND PRESENTATION

The data used for this analysis were confined to those data assumed to be free of observational, coding, and transmission errors.

Monthly averages of temperature have been computed for each one-degree Marsden Square. These data have been analyzed as shown in succeeding sections (see Figures 4-41). The monthly temperature averages are displayed in Appendix A to facilitate the reader's evaluation of each analysis. Monthly averages were used rather than seasonal averages because it appears that sufficient data are available for meaningful analysis during at least one month per season of the year. On the other hand, the use of seasonal averages would tend to smooth any salient features in a similar presentation, even though it might improve the density of data available.

A. TEMPERATURE ANALYSIS

1. Surface Level

Skogsberg (1936) in his study of the thermal structure of Monterey Bay concluded that a thin layer of sea water was greatly affected by seasonal variations in heating. Wolff (1966) showed a breakdown of factors affecting sea surface temperature and their possible magnitude (see Table 1).

Tabata (1964) also concludes that cloud amount and sun's altitude have a significant effect on direct and diffuse radiation and ultimately on-sea surface temperature for the regions around 50 N, 145 W. This concept is assumed to apply in the area under investigation in this paper.

Table 1

Factors Affecting the Sea Surface Temperature (SST) and Some Typical Values of SST Changes Caused by Them in 48 Hours.

Basic Cause	Processes and factors	Assumed value for computation of change in 48 hours	Possible SST change in 48 hours, F
	Permanent (gradient) flow	Speed 1 knot, SST gradient 3F/100n. miles	1.4
Advection	Wind Currents	Speed 0.4 knots, SST gradient 3F/100n. miles	0.4
	Inertia and tidal currents	Speed 0.4 knots, SST gradient 6F/100n. miles	0.7
	Insolation (affected) by clouds	600 g.cal.cm 24h, MLD 50 feet	1.4
Heat Exchange	Evaporation (affected) by wind and c c	300 g.cal.cm 24h, MLD 50 feet	0.7
	Other heat exchange components	200 g.cal.cm 24h,	0.5
	Wave action	Deepening of shallow MLD by 25' with sharp gradient below	3.0
Mixing	Convective stirring	Dependent on heat loss	1.0
	Currents	Dependent of sharpness of boundaries	0.3
	Upwelling and divergence/convergence	Gradient 5F/100 feet divergence 50 feet	(2.5)
Special Causes	Runoff	Important off estuaries	(0.5)
	Precipitation	(Important only in case of snow and hail)	(0.2)
	Freezing and melting	(Important in limited areas in high latitudes)	(3.0)

To distinguish these factors from other factors affecting the vertical profile at lower levels, it was necessary to analyze the temperature at the sea surface.

2. 10-Meter Level

Lynn (1967) in his study of the variability of temperature and density of the California Current system chose the 10-meter level for analysis, assuming it to be free of the transient conditions affecting the surface layer. For this reason, the 10-meter level was selected to filter out surface temperature variability due to transient atmospheric conditions.

3. 100-Meter Level

South of 31 N Tully (1964) classifies the environment to be Subtropic. The seasonal thermocline in this region has a lower limit of 150 meters. It is assumed in this presentation that any change in temperature at the 100-meter level probably is due to upwelling of deeper water masses, north of 31 N. South of 31 N seasonal variability of temperature must be taken into account before this assumption is made.

B. TEMPERATURE-SALINITY ANALYSIS

A temperature-salinity analysis was used to verify areas where temperature analysis indicated the existence of probable upwelling areas.

C. CRITERIA TO DETERMINE UPWELLING

The criteria used to determine if upwelling was actually taking place was based on the following tests:

1. Is there an indicated low temperature area adjacent to the coast? Sverdrup and Fleming (1942).

2. Is there a reasonable temperature range between the 100-meter level and surface? (Approximately 4-5 degrees centigrade.) Skogsberg (1936).

3. Is the temperature at the 100-meter level lower than normally would be expected? See Table 2 below.

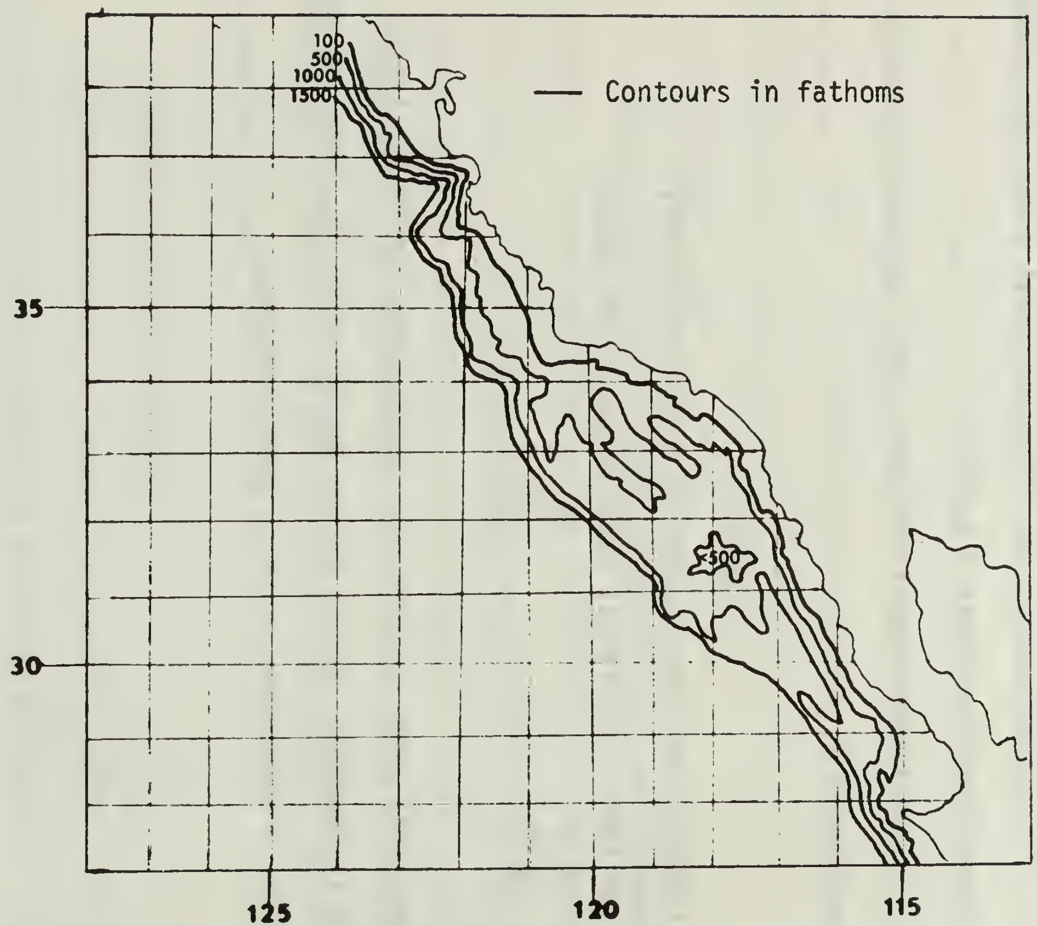
4. Is there coastal shelf influence which may modify results of (3)? (See Fig. 3.)

Table 2

Extrapolated from Studies by Reid (1960, 1965).

Latitude	Critical Temperature at 100 Meters
37 N	9.7 C
32 N	10.1 C
27 N	10.5-11.5 C

If the first three criteria are affirmative, or if the third criterion is negative because of the fourth criterion, then the area in question is determined to be an upwelling area.



Continental shelf contours along the California coast

Figure 3

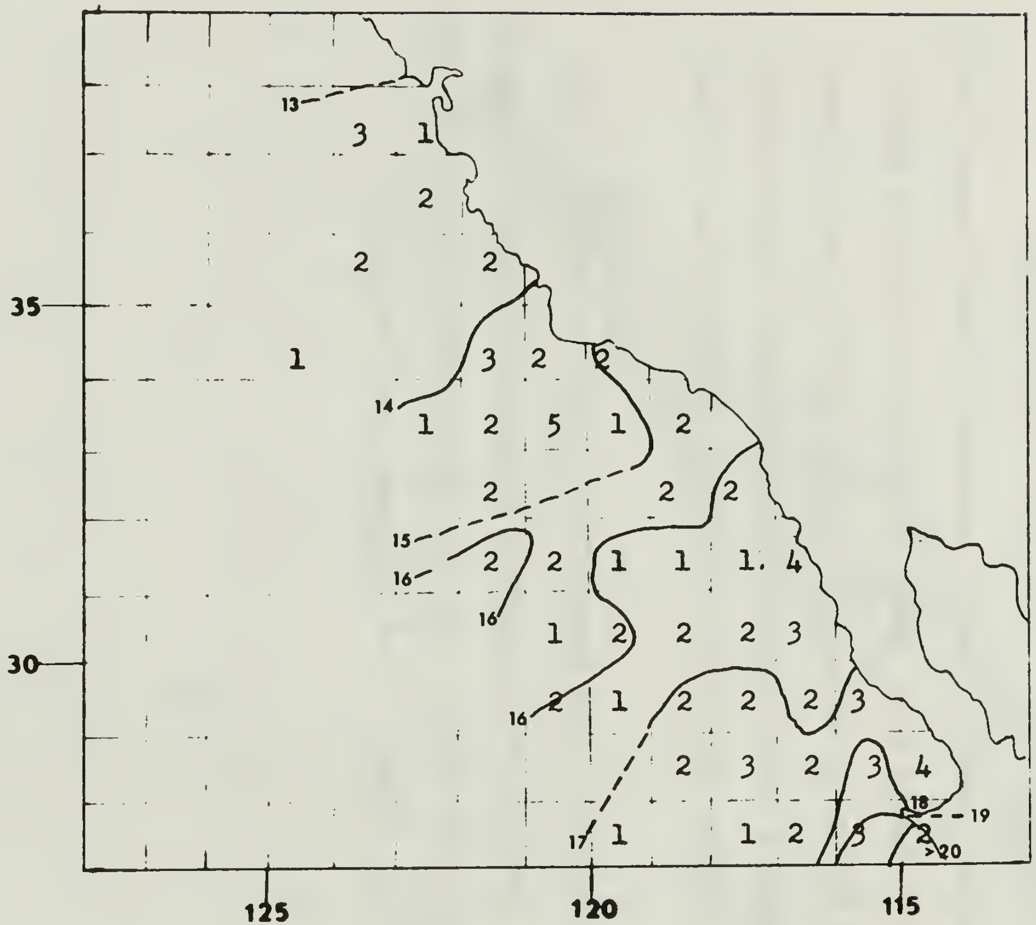
III. TEMPERATURE AND DENSITY ANALYSIS

The figures in this section display the temperature structure along the California coast from 27-37 N. All isotherms are in degrees centigrade. The figures are arranqed by month showing the surface, 10-meter and 100-meter levels in order. The data on which each analysis is based are provided in corresponding order in Appendix A to facilitate the reader's evaluation of each analysis.

The numbers appearing in the one-degree Marsden Squares indicate the number of Nansen casts taken in that area during the month.

Dotted isothermal lines indicate that insufficient data were available during that particular month for analysis and that the isothermal pattern was extrapolated from general trends in other months.

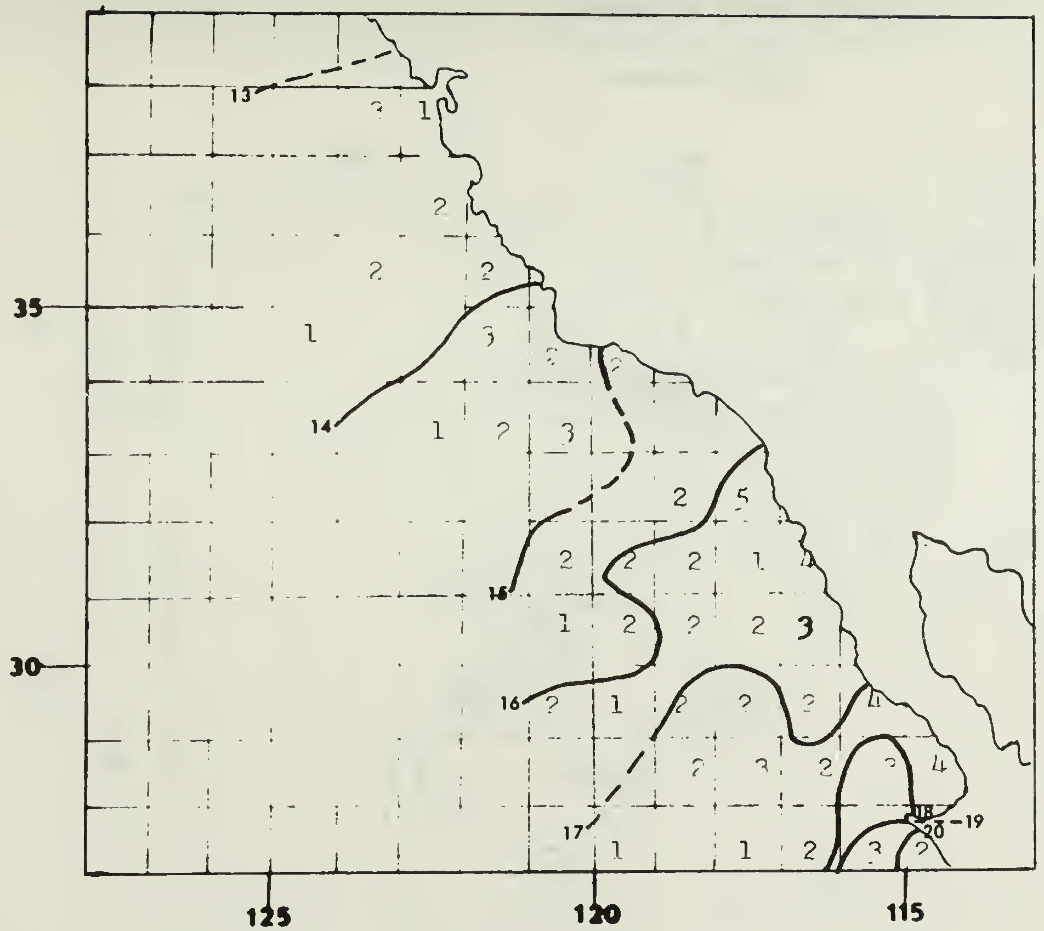
Areas that show a low temperature adjacent to the coast line are shaded grey and are analyzed on a temperature-salinity diagram which follows each month. This plot uses temperature-salinity data at the surface, 10-meter, and 100-meter level for analysis.



January 1958

Surface isotherms

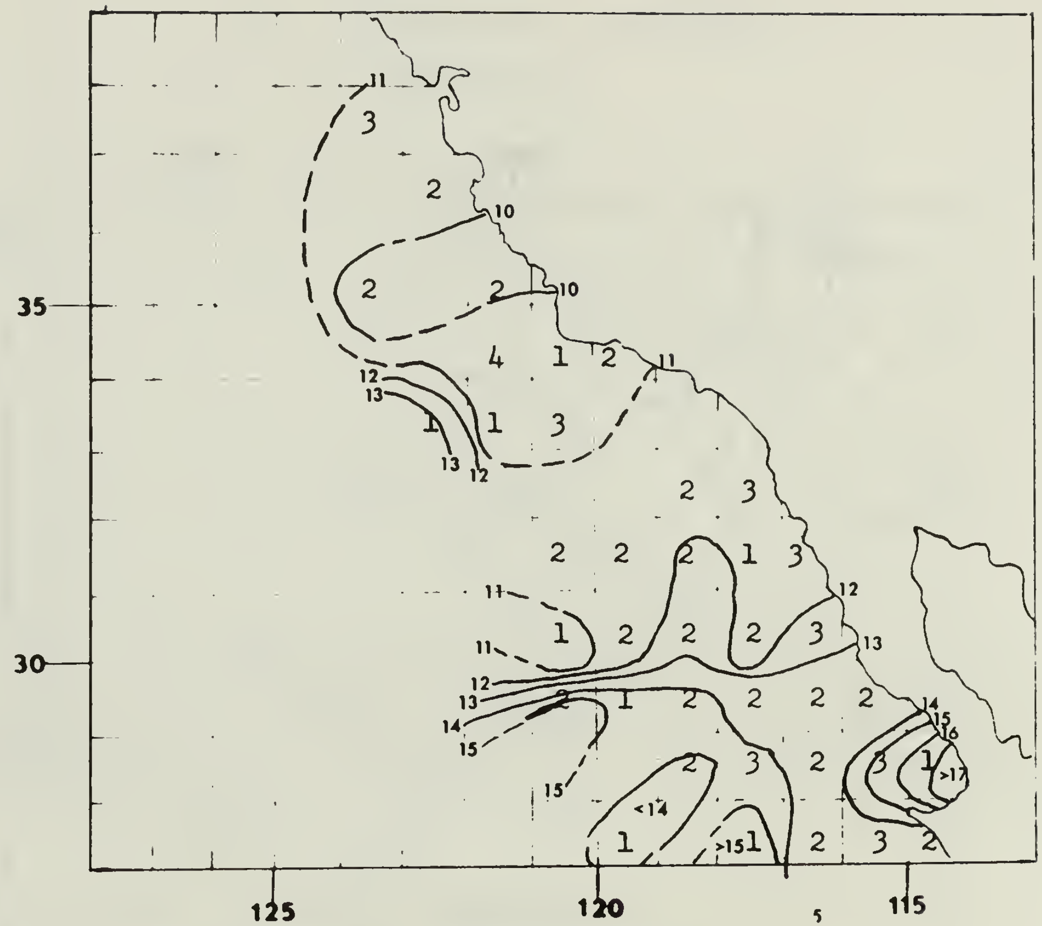
Figure 4a.



January 1958

10-meter level isotherms

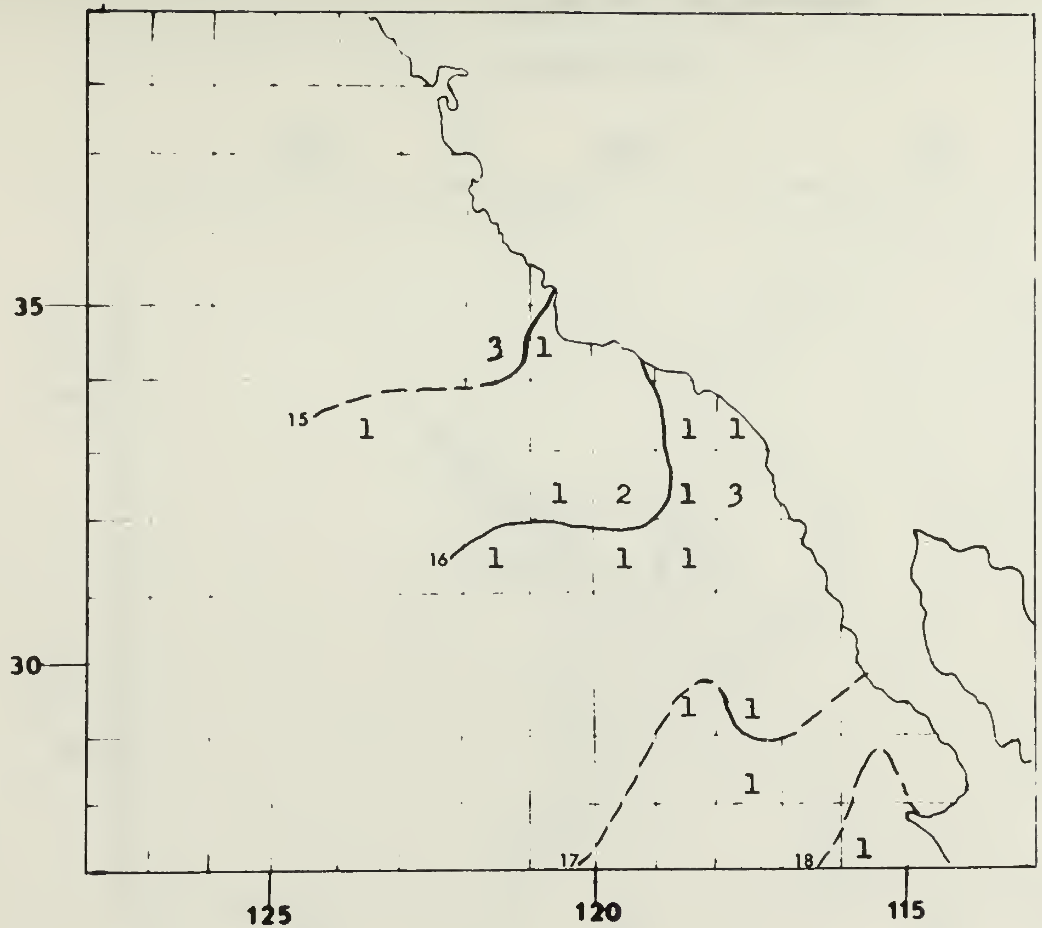
Figure 4b.



January 1958

100-meter level isotherms

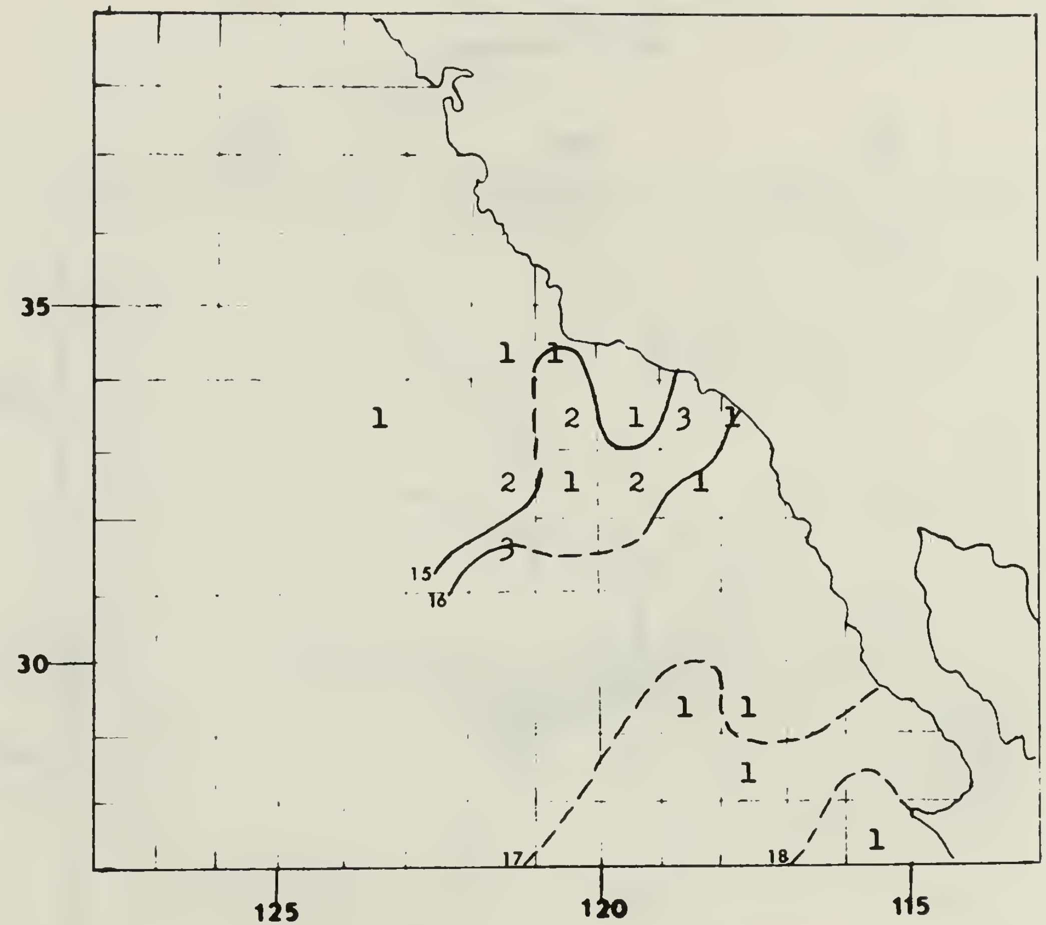
Figure 4c.



February 1958

Surface isotherms

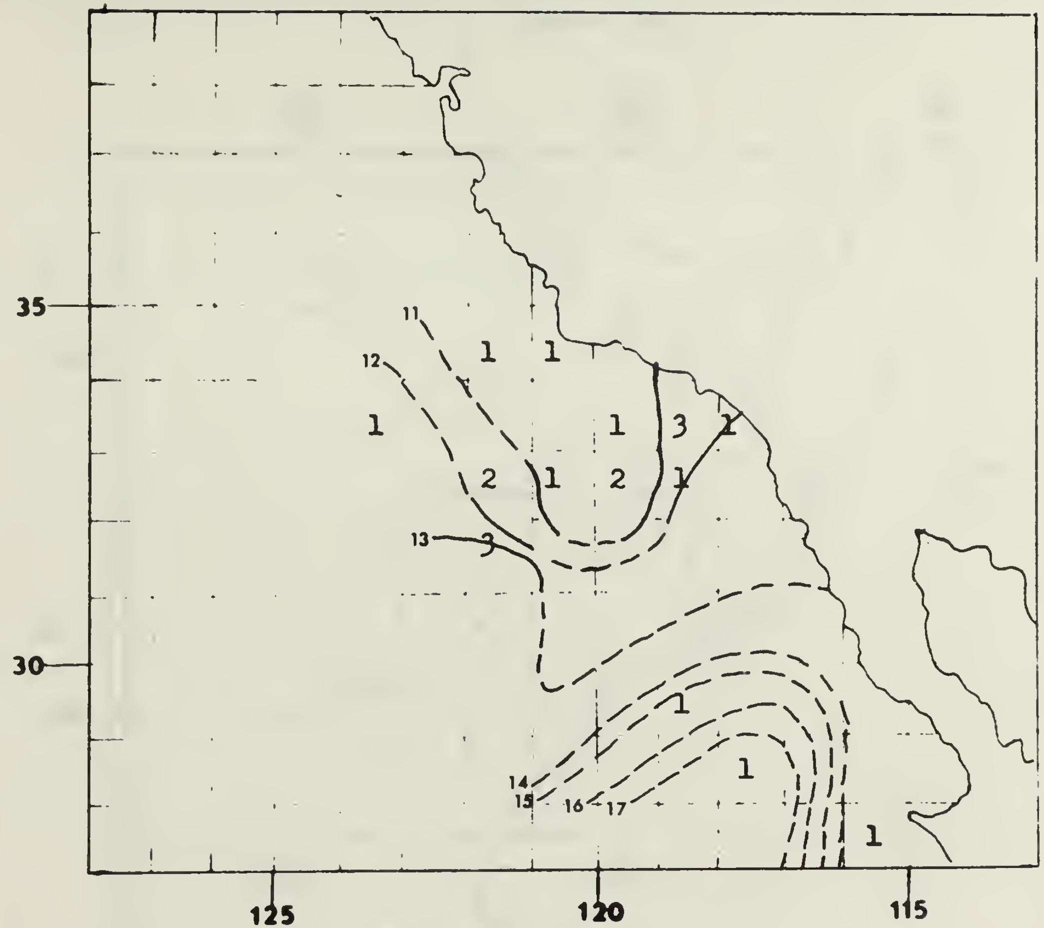
Figure 5a.



February 1958

10-meter levelisotherms

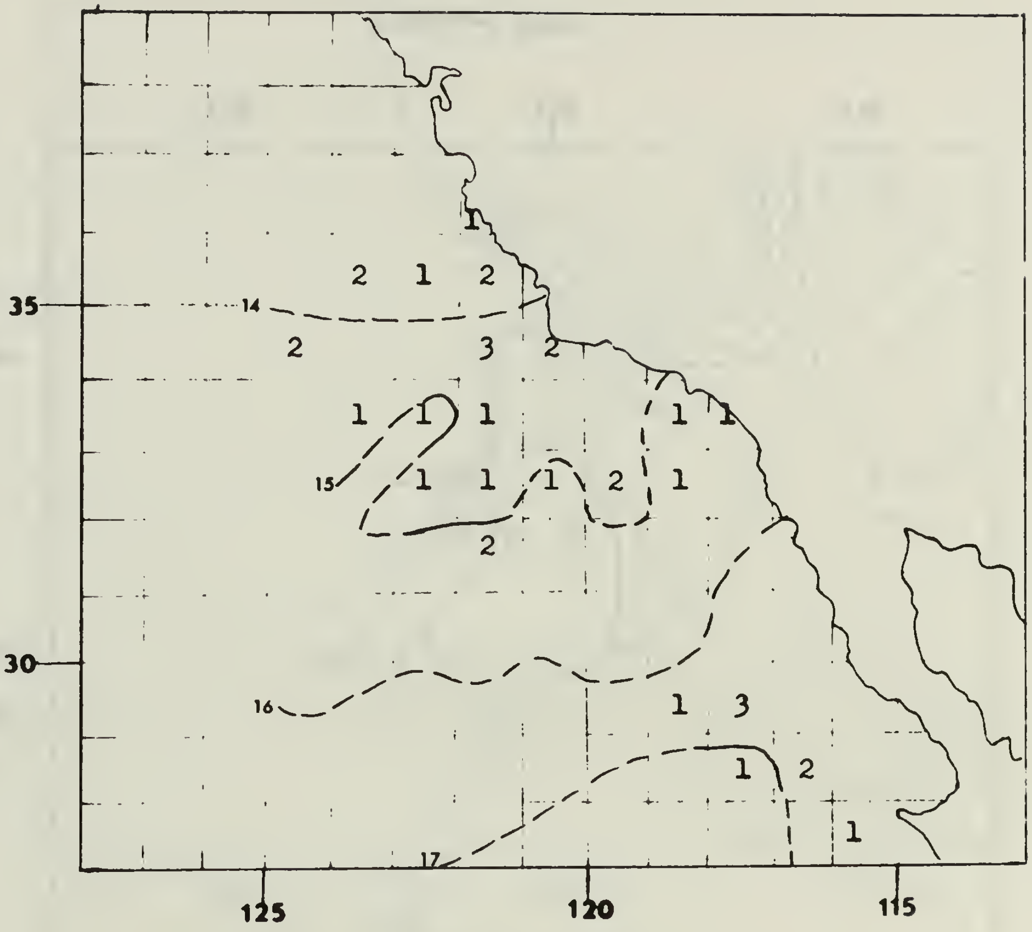
Figure 5b.



February 1958

100-meter level isotherms

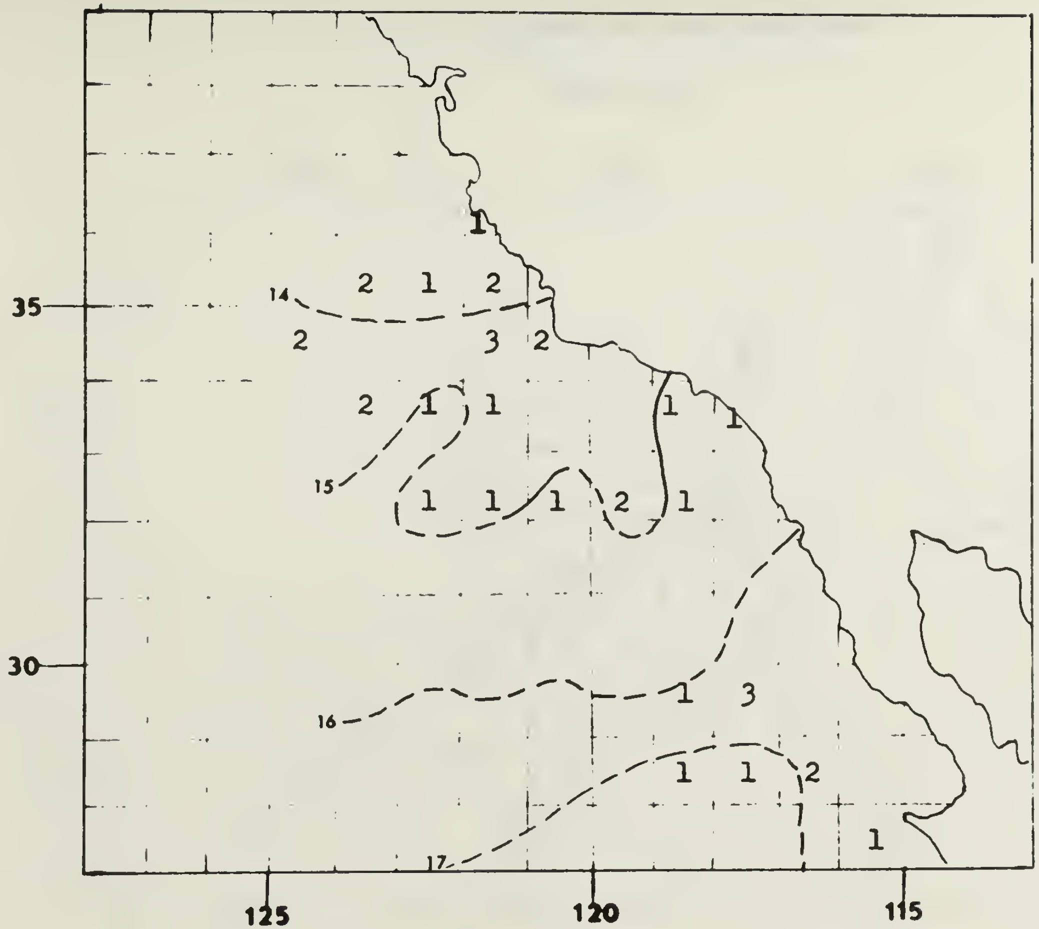
Figure 5c.



March 1958

Surfaee isotherms

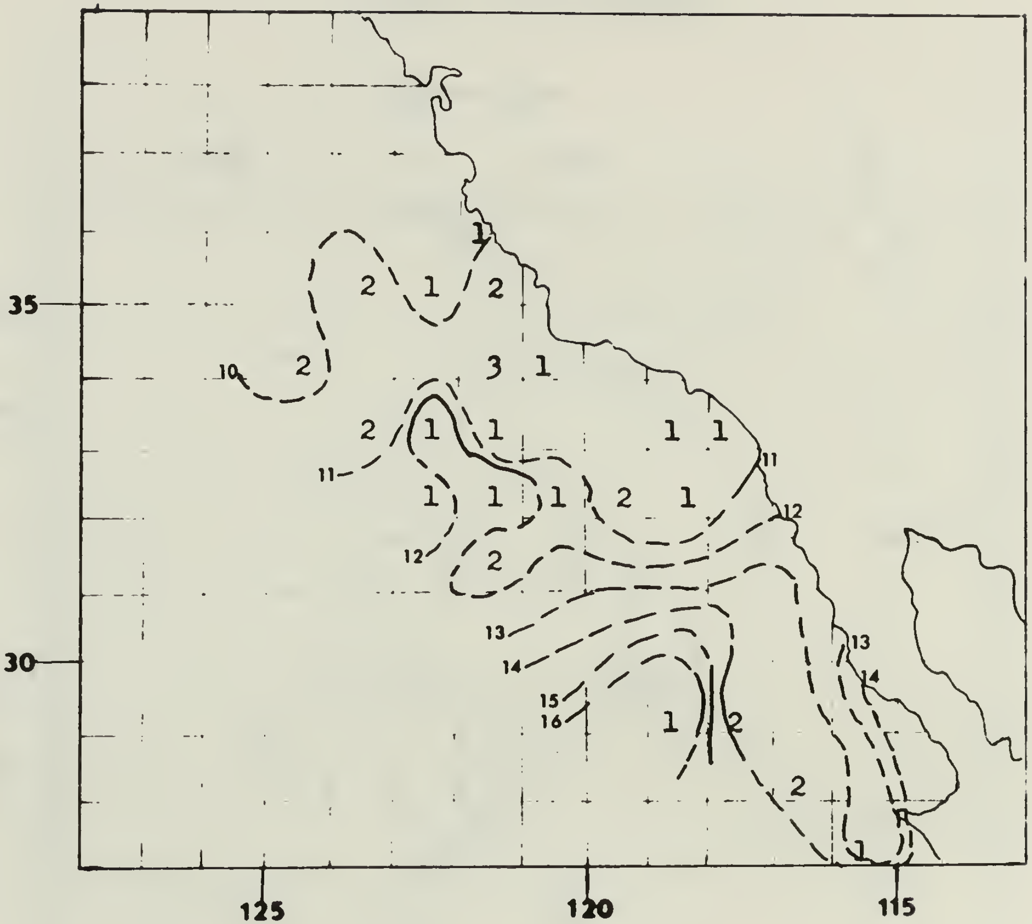
Figure 6a.



March 1958

10-meter level isotherms

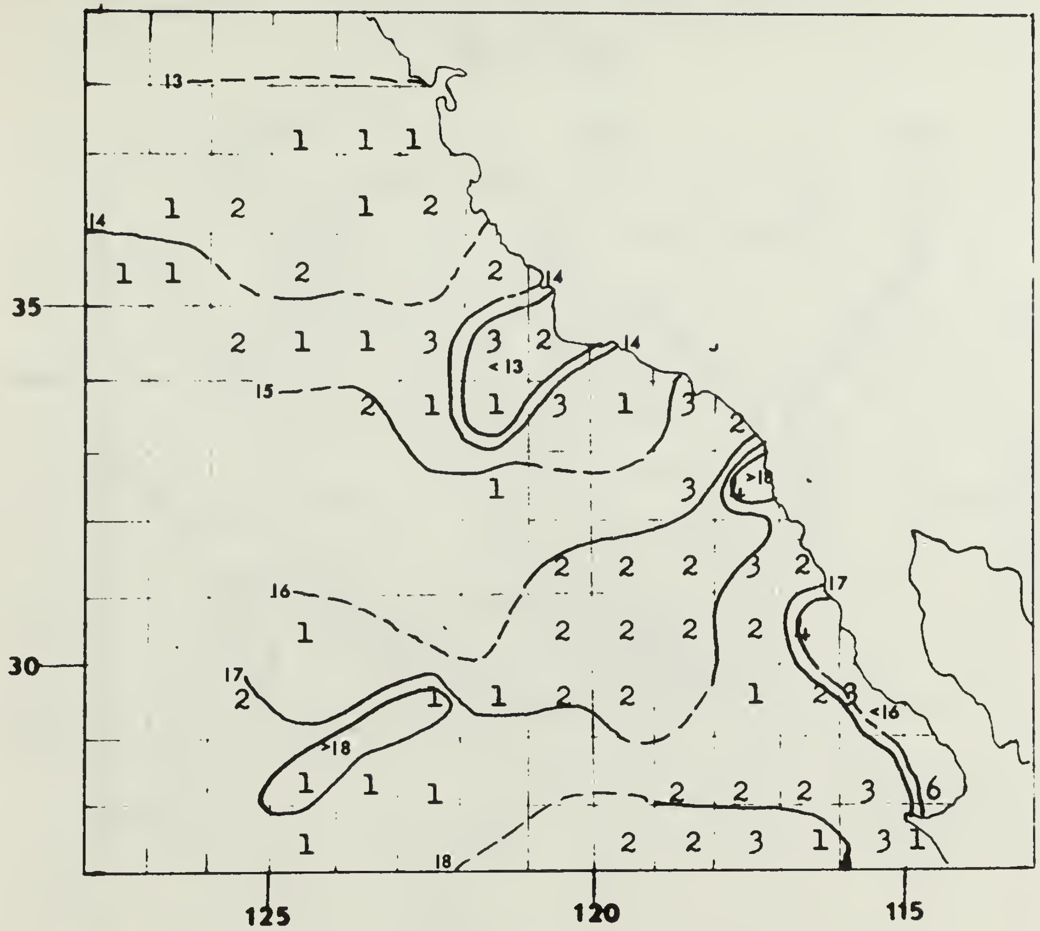
Figure 6b.



March 1958

100-meter level isotherms

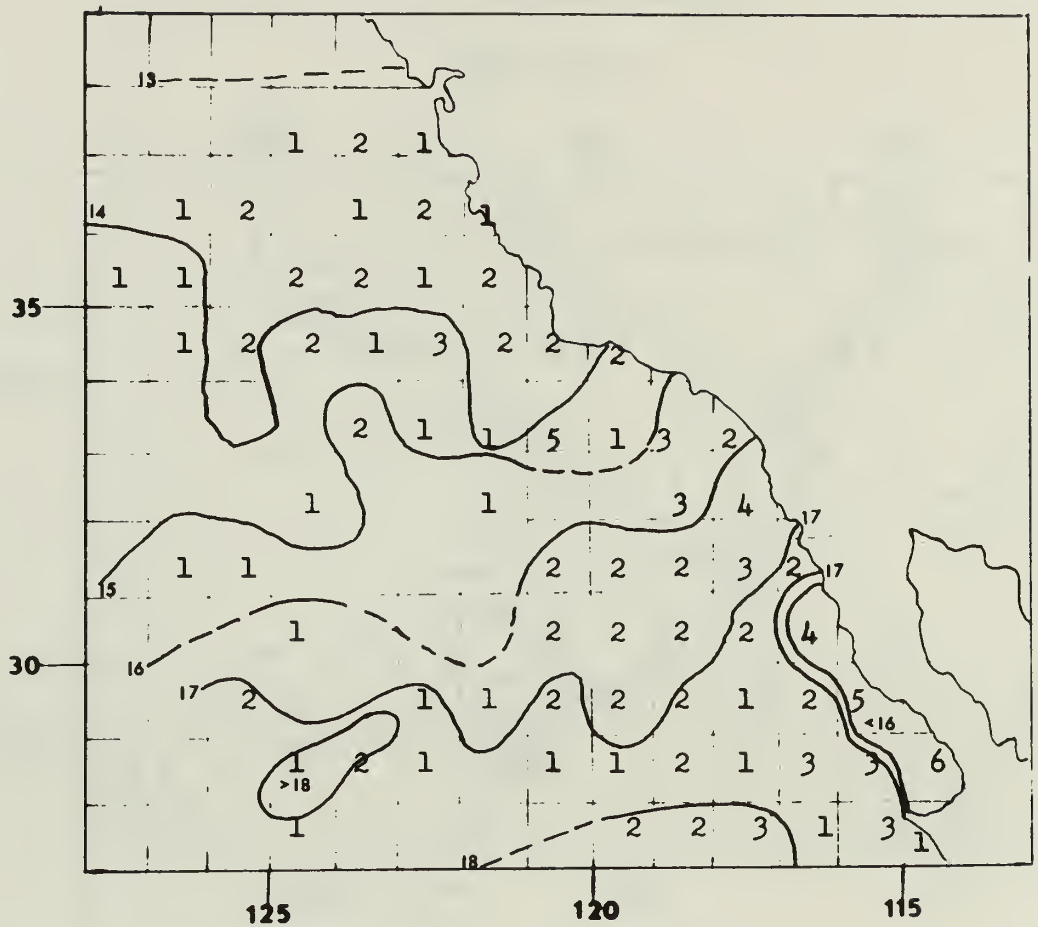
Figure 6c.



April 1958

Surface isotherms

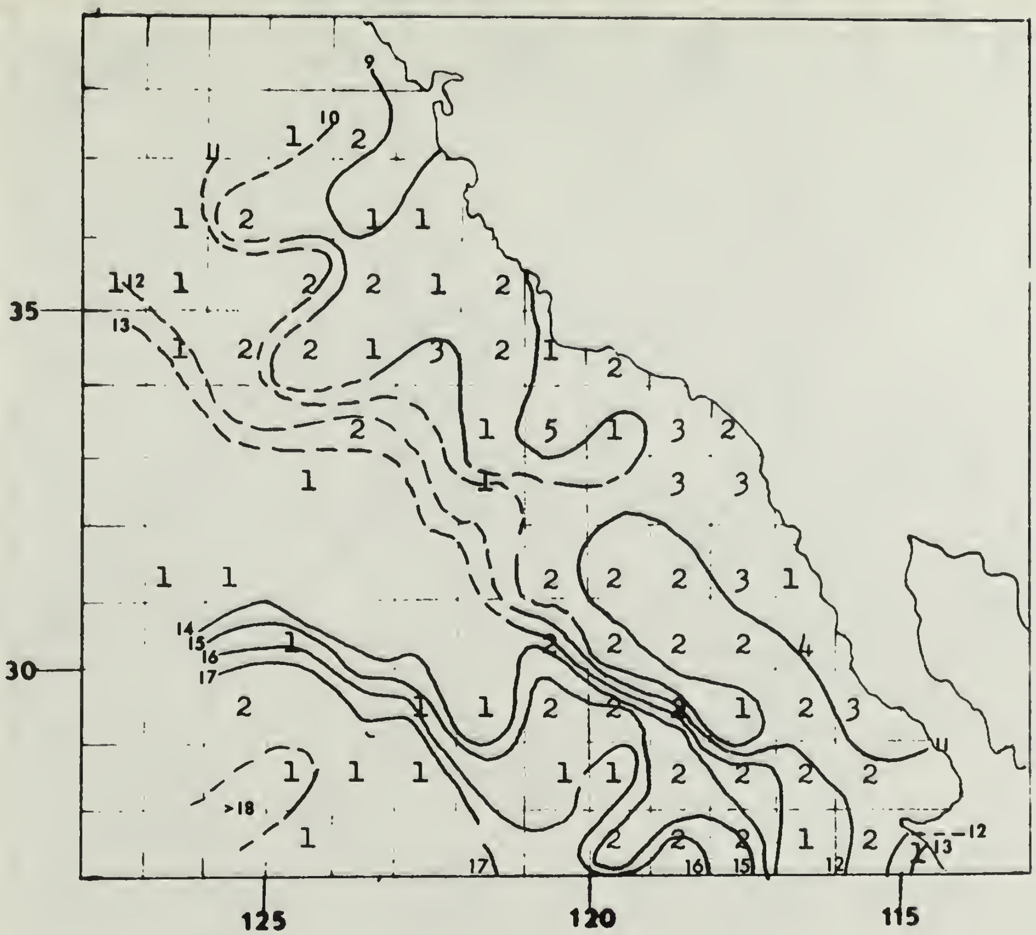
Figure 7a.



April 1958

10-meter level isotherms

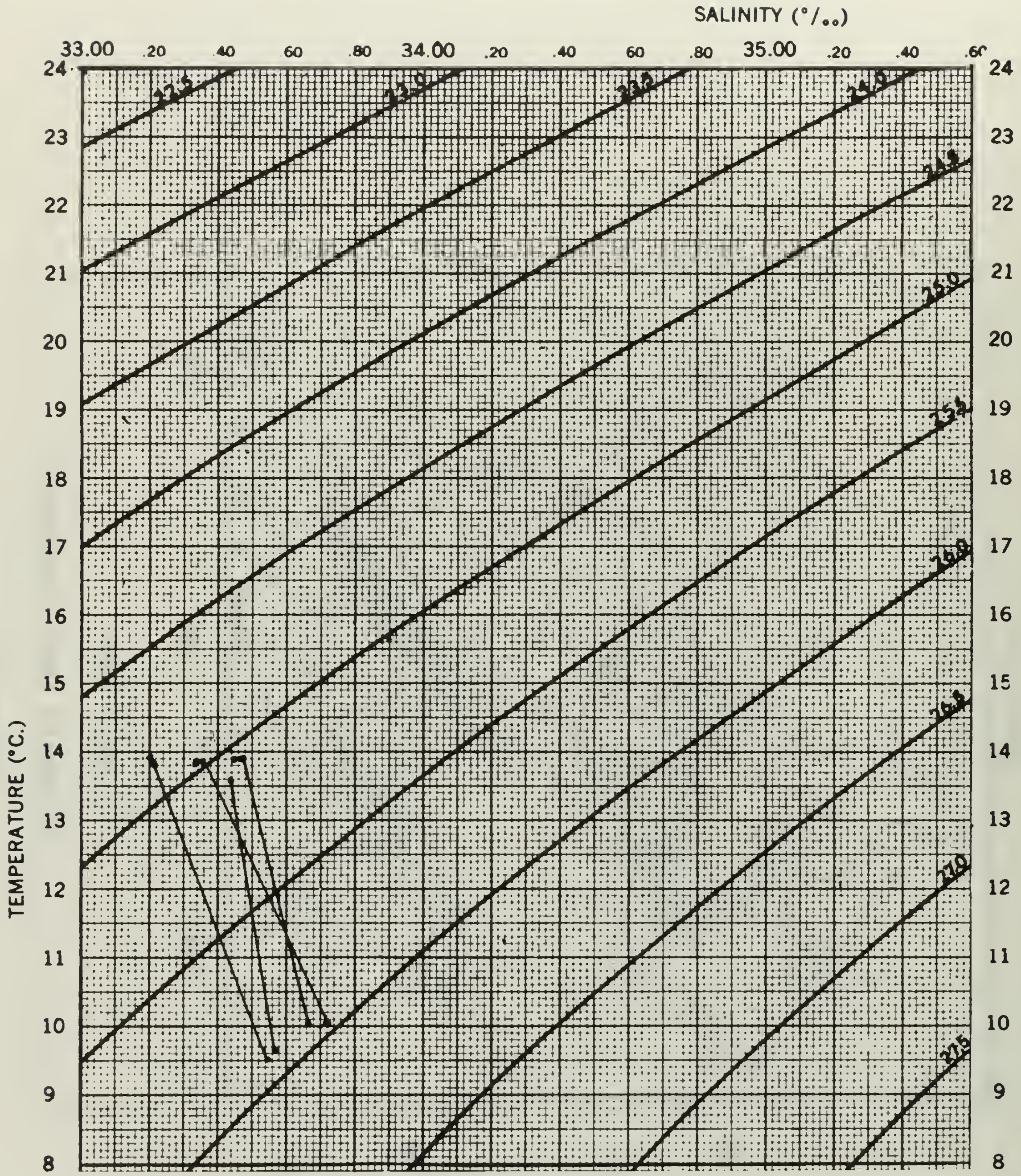
Figure 7b.



April 1958

100-meter level isotherms

Figure 7c.

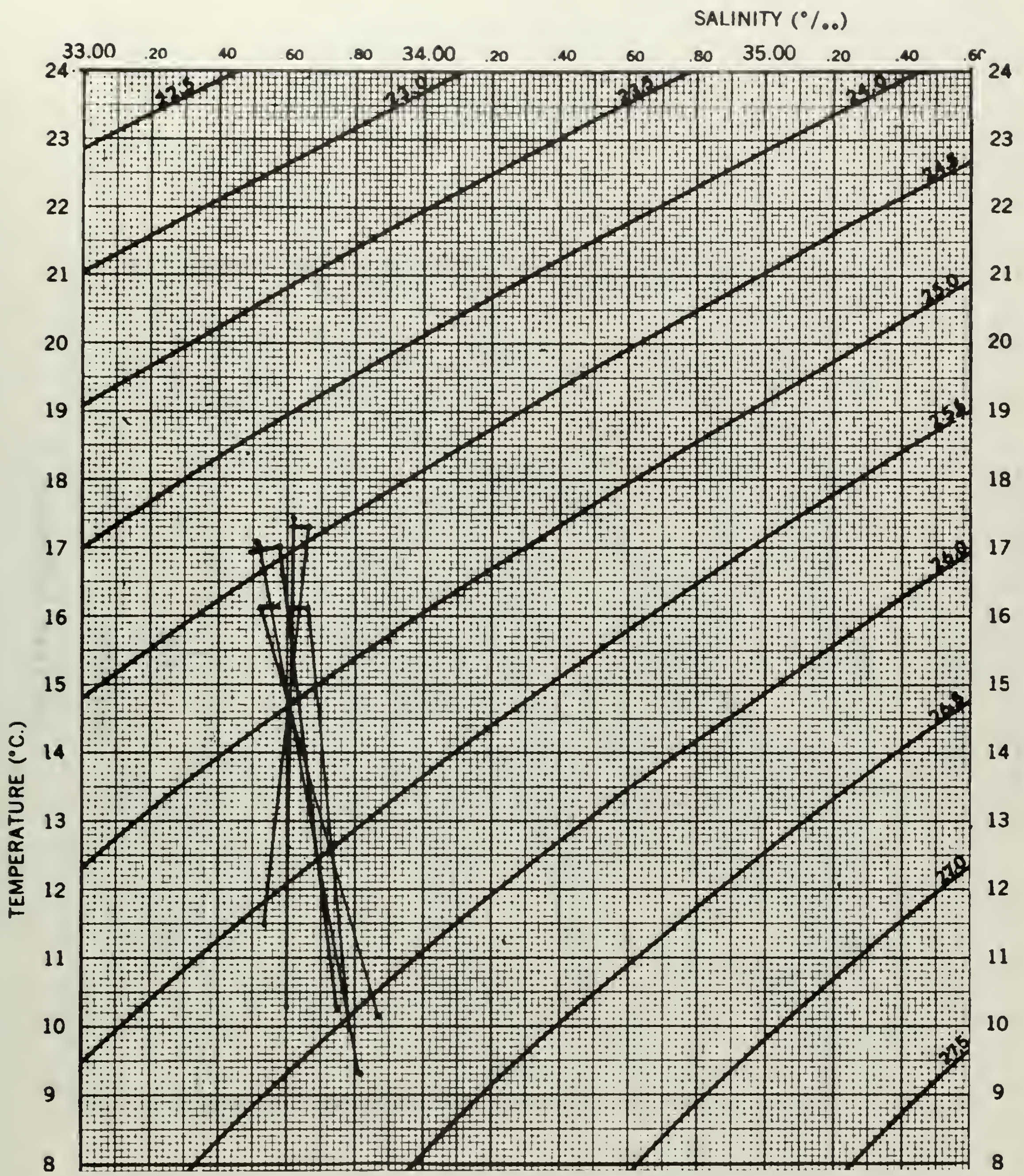


UPWELLING AREA

April 1958

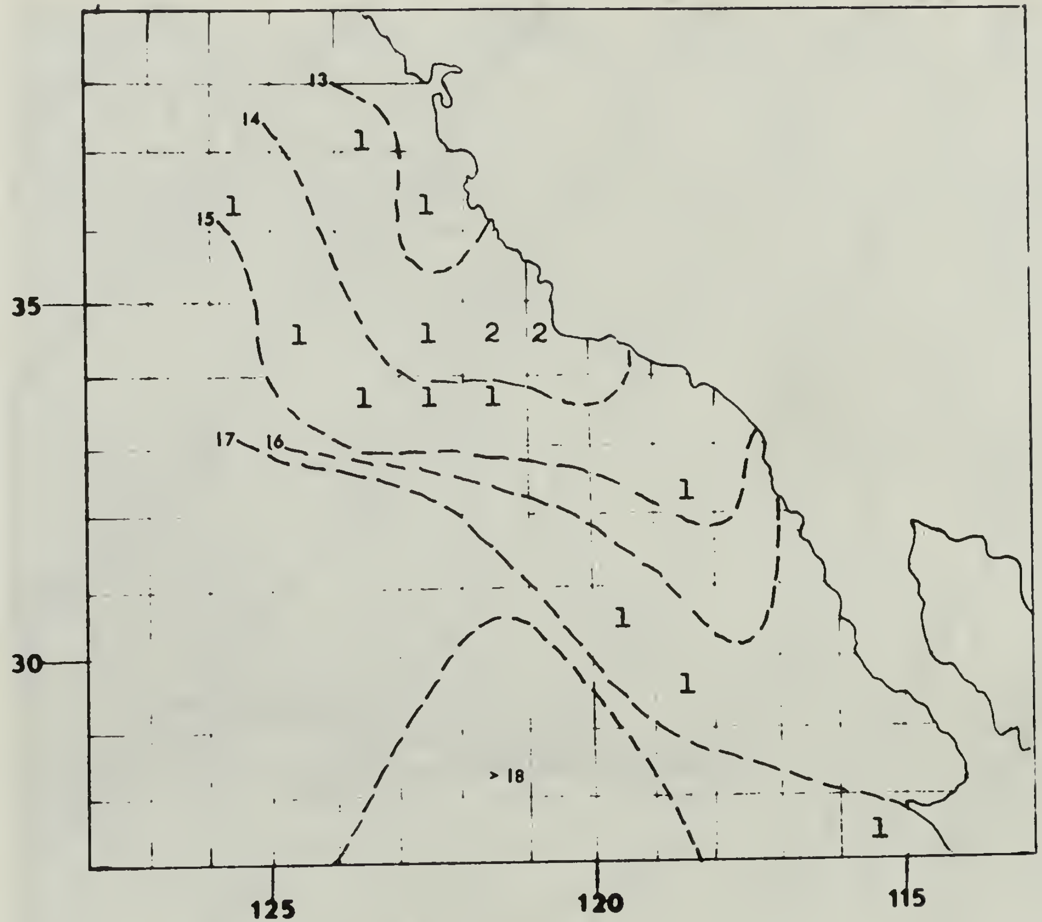
34 N-120 W
34 N-121 W
33 N-121 W

Figure 8a



UPWELLING AREA
April 1958
30 N-116 W
29 N-115 W
(28 N-114 W)

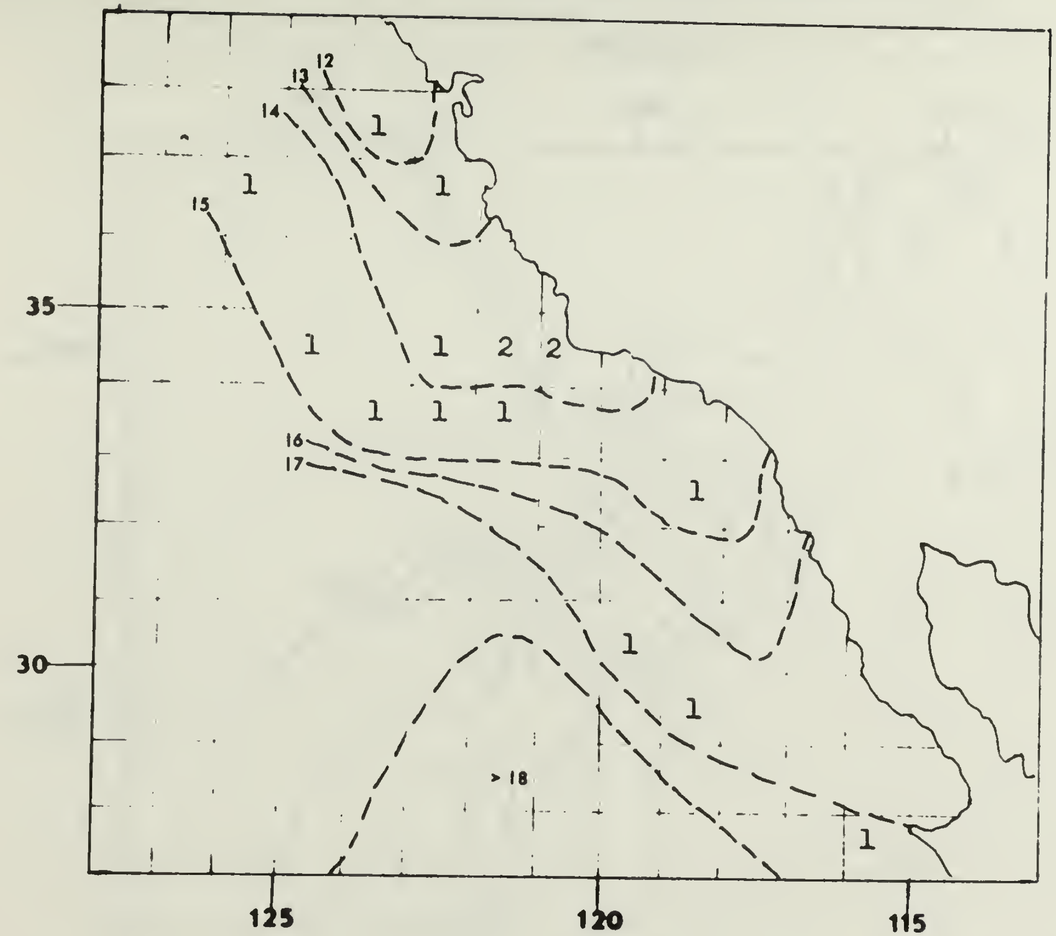
Figure 8b.



May 1958

Surface isotherms

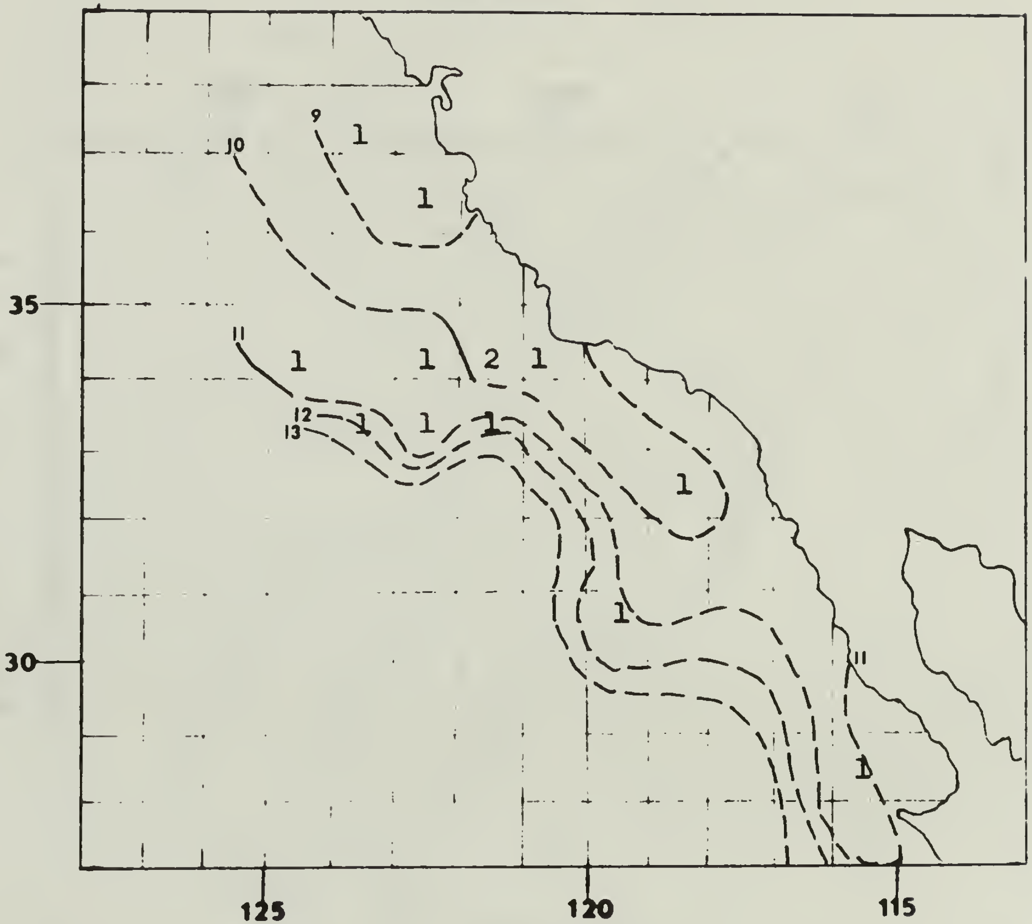
Figure 9a.



May 1958

10-meter level isotherms

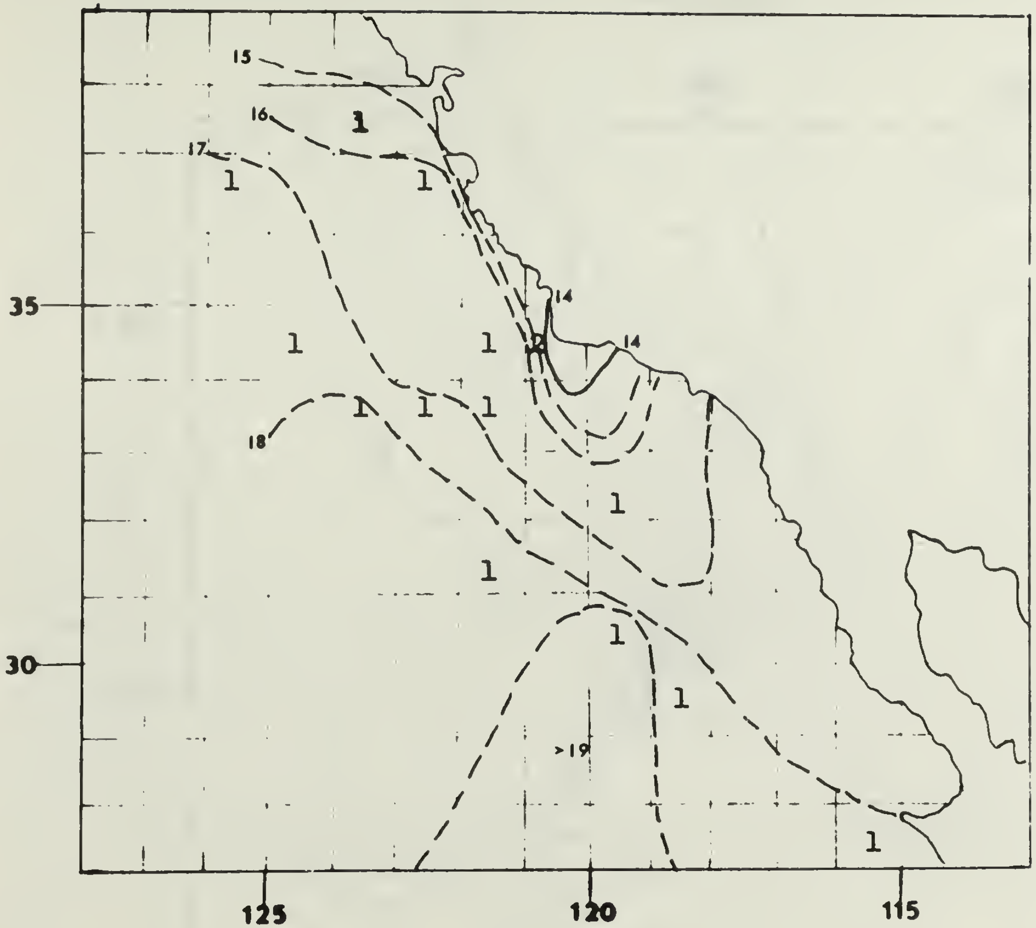
Figure 9b.



May 1958

100-meter level isotherms

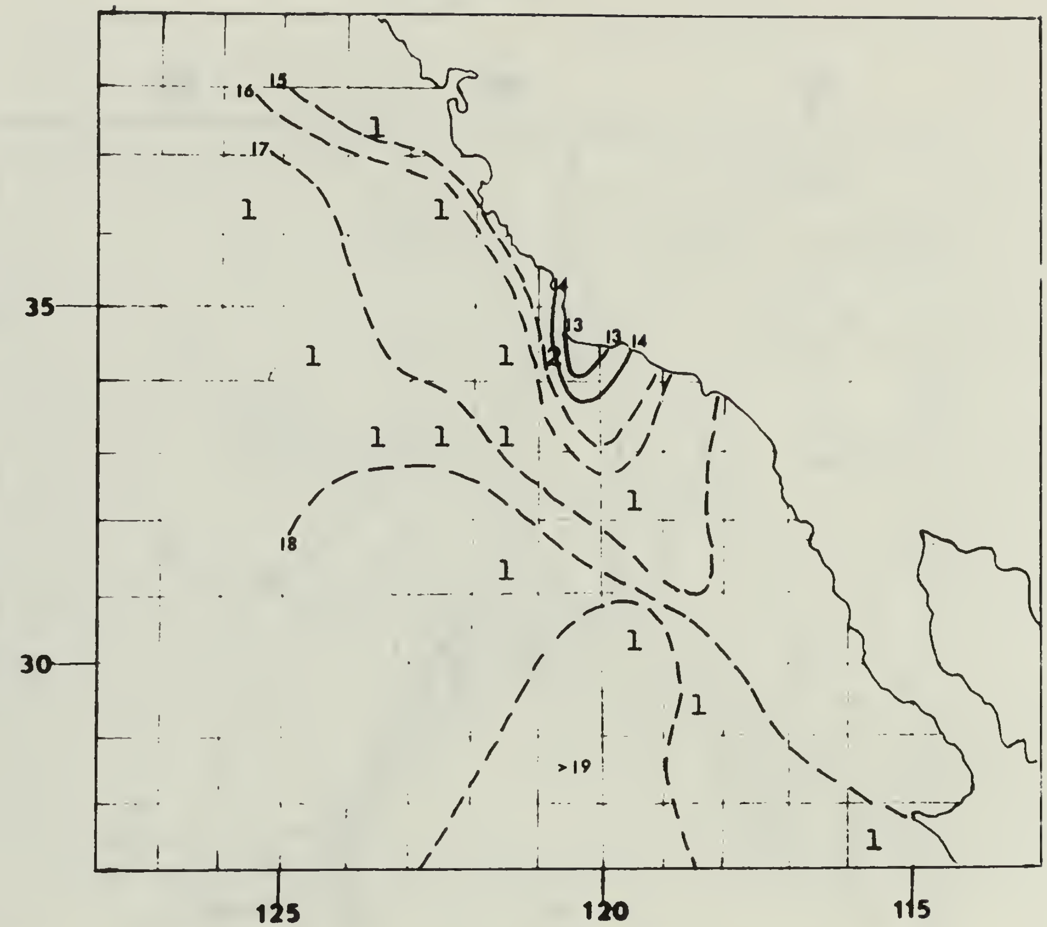
Figure 9c.



June 1958

Surface isotherms

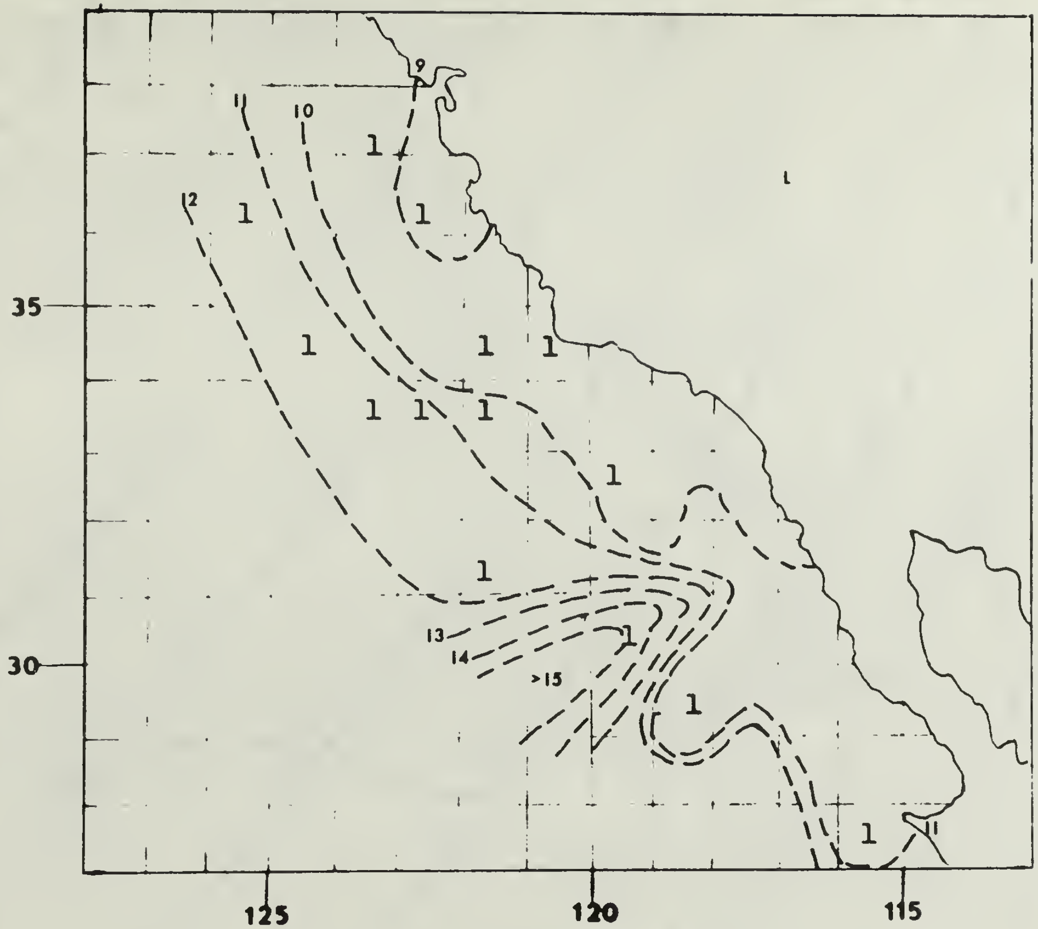
Figure 10a.



June 1958

10-meter level isotherms

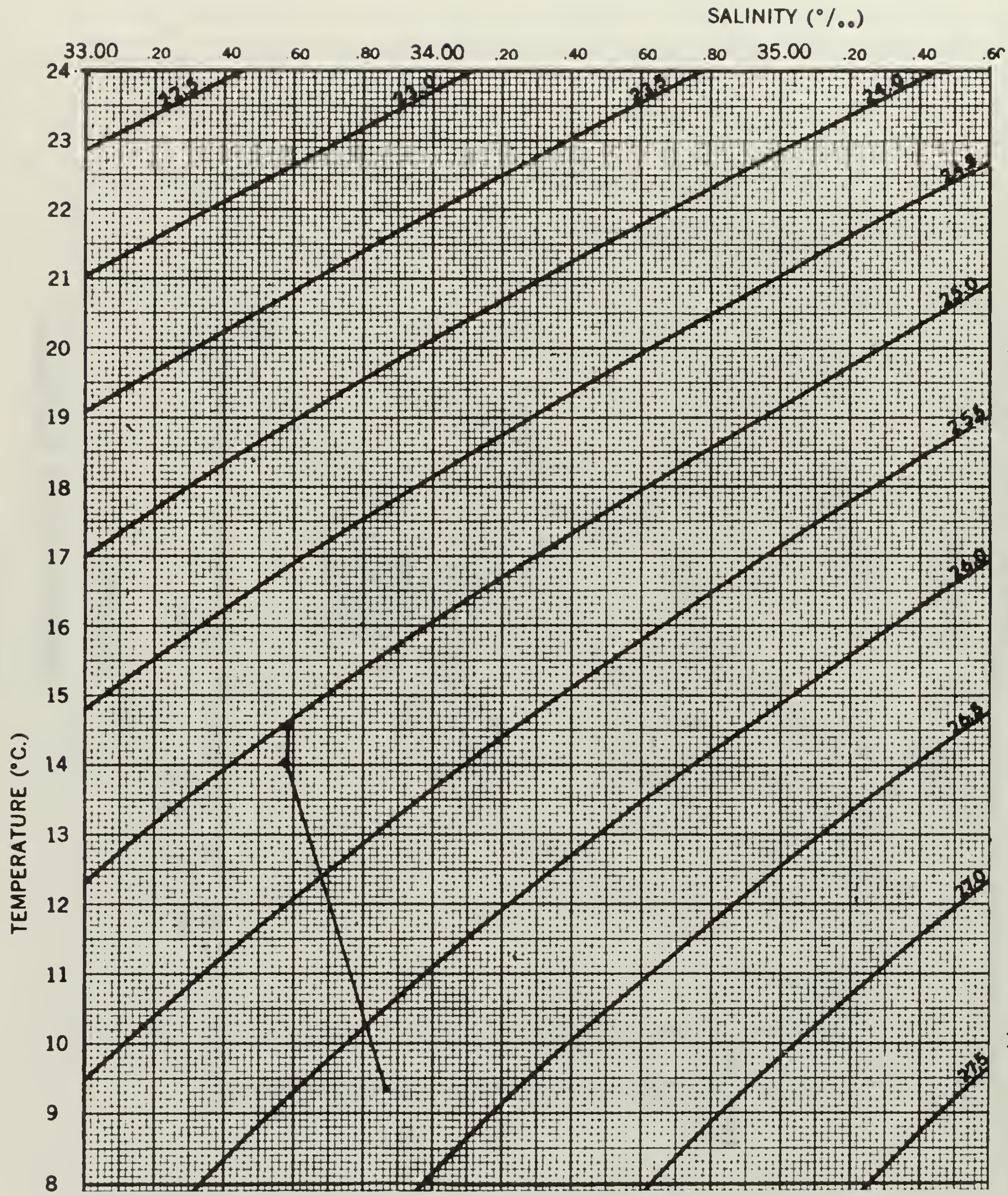
Figure 10b.



June 1958

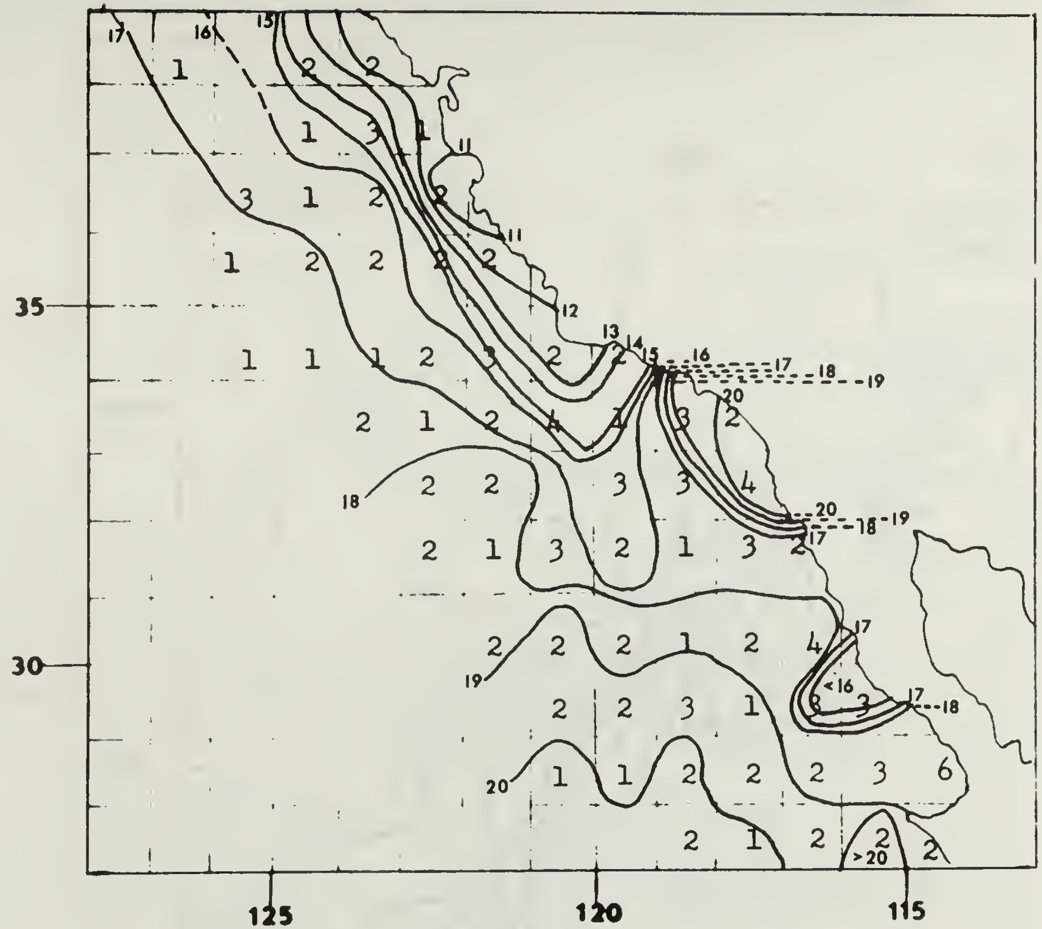
100-meter level isotherms

Figure 10c.



UPWELLING AREA
June 1958
34 N-120 W

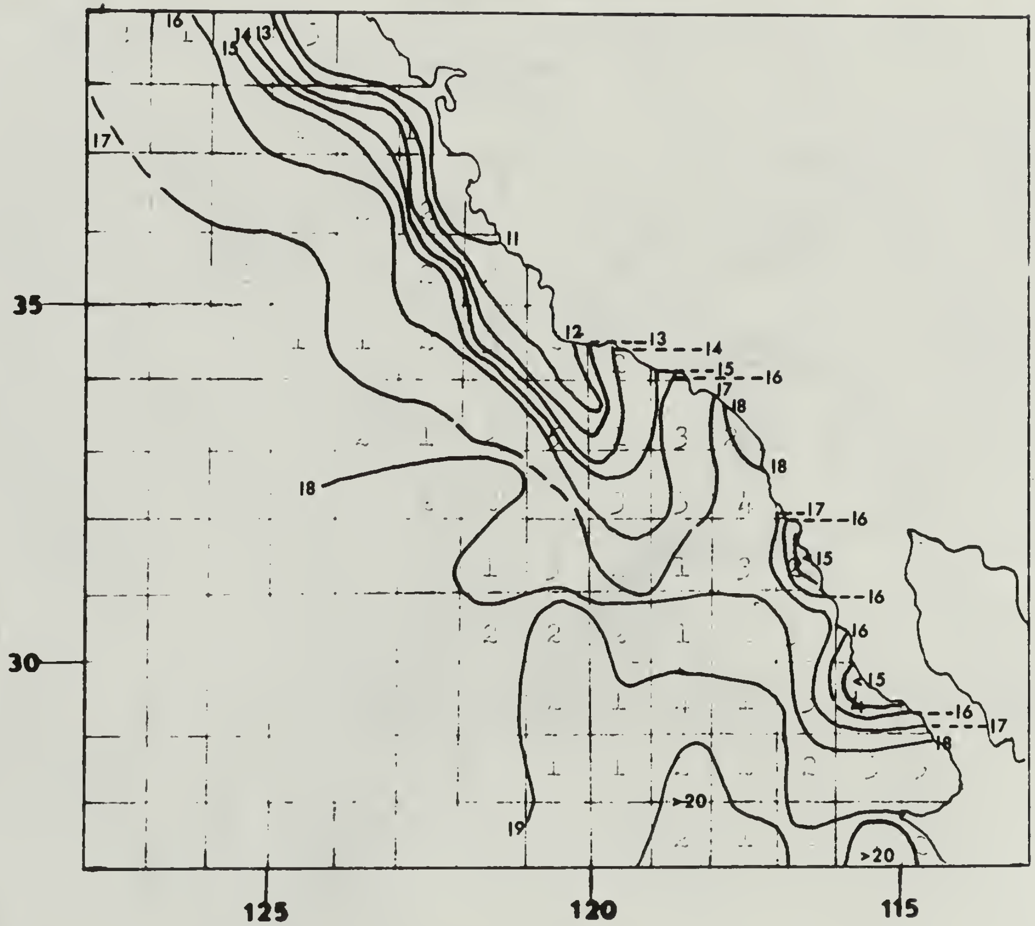
Figure 11a.



July 1958

Surface isotherms

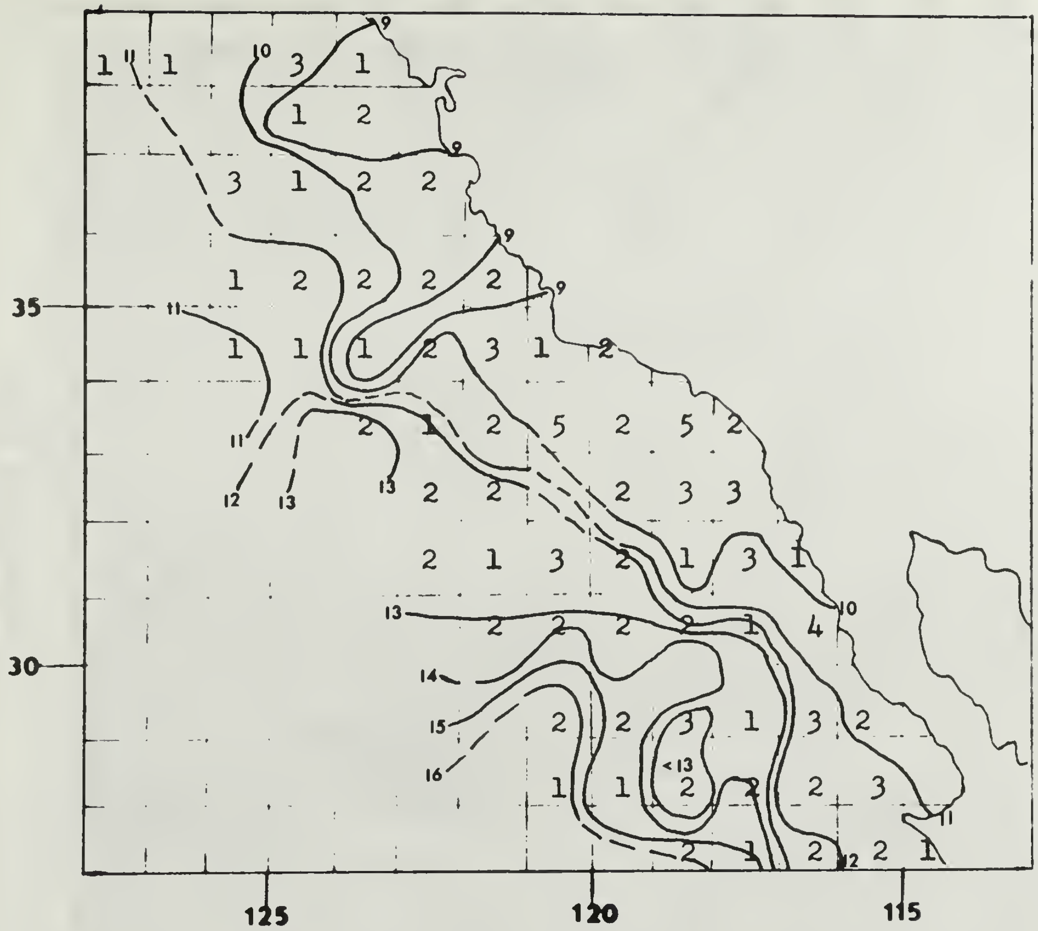
Figure 12a.



July 1953

10-meter level isotherms

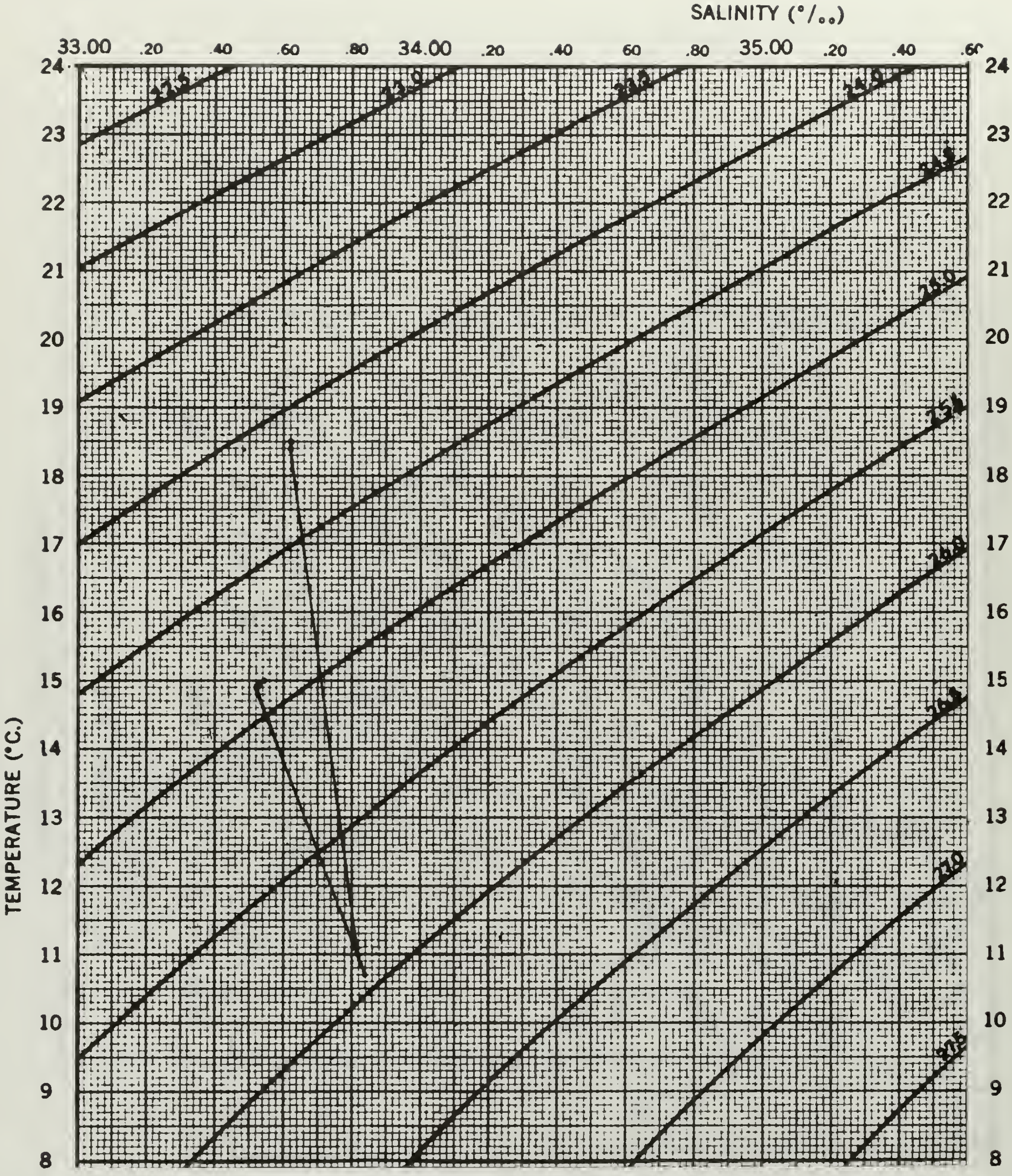
Figure 12b



July 1958

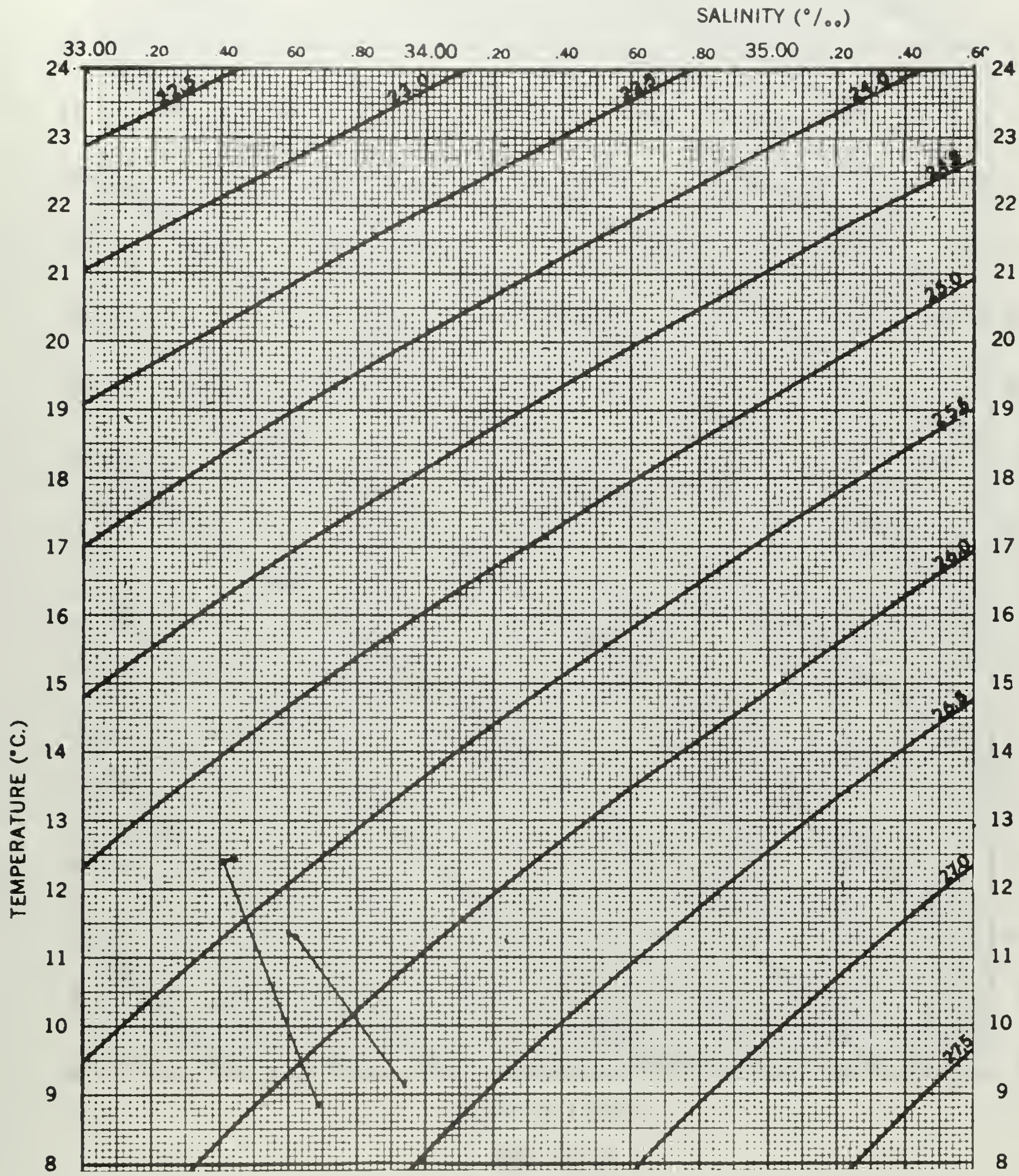
100-meter level isotherms

Figure 12c.



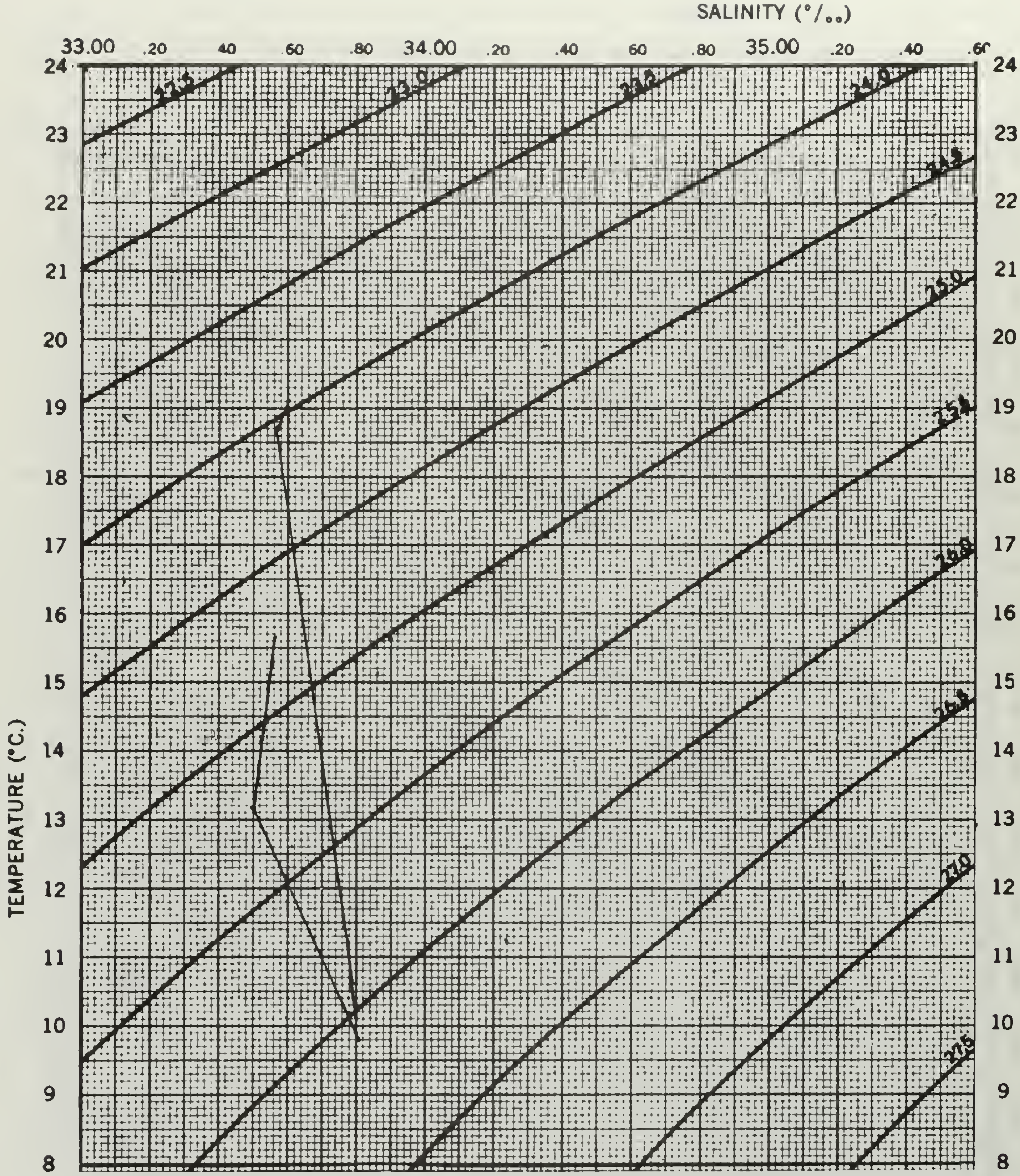
UPWELLING AREA
July 1958
29 N-115 W

Figure 13a.



UPWELLING AREA
July 1958
36 N-122 W

Figure 13b.

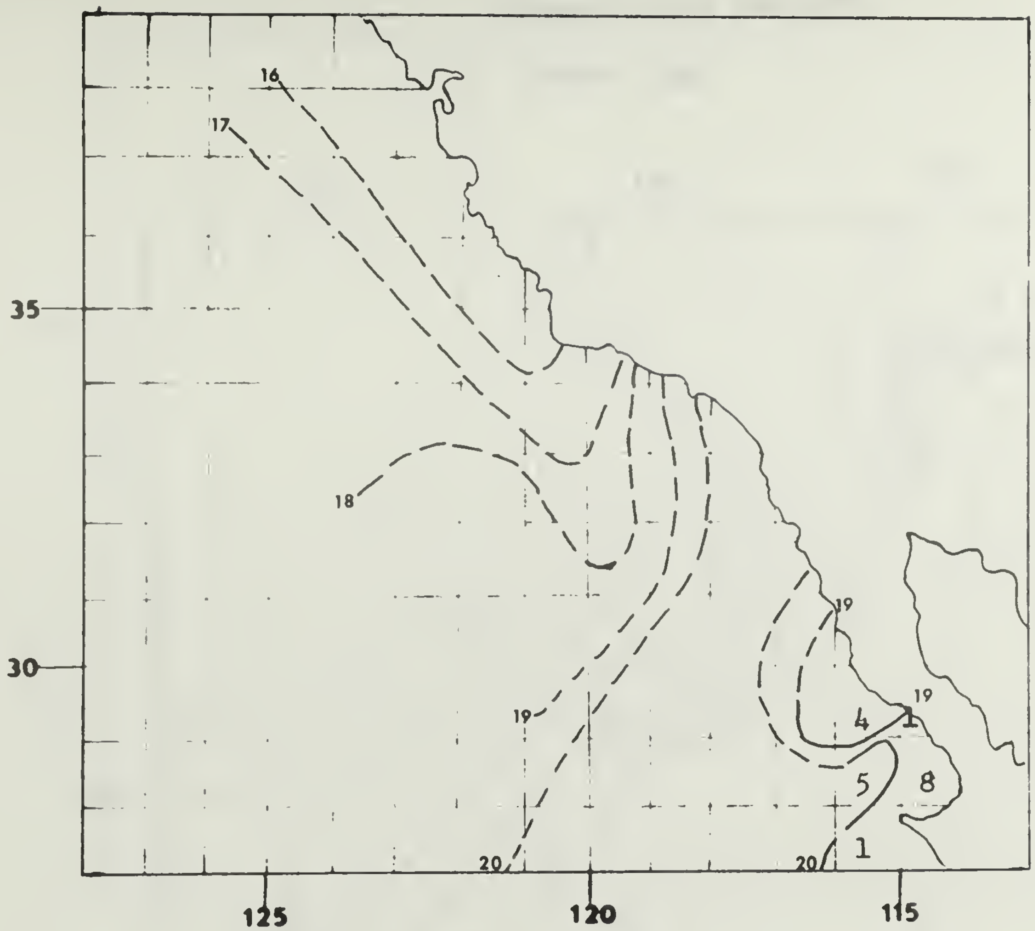


UPWELLING AREA

July 1958

31 N-116 W

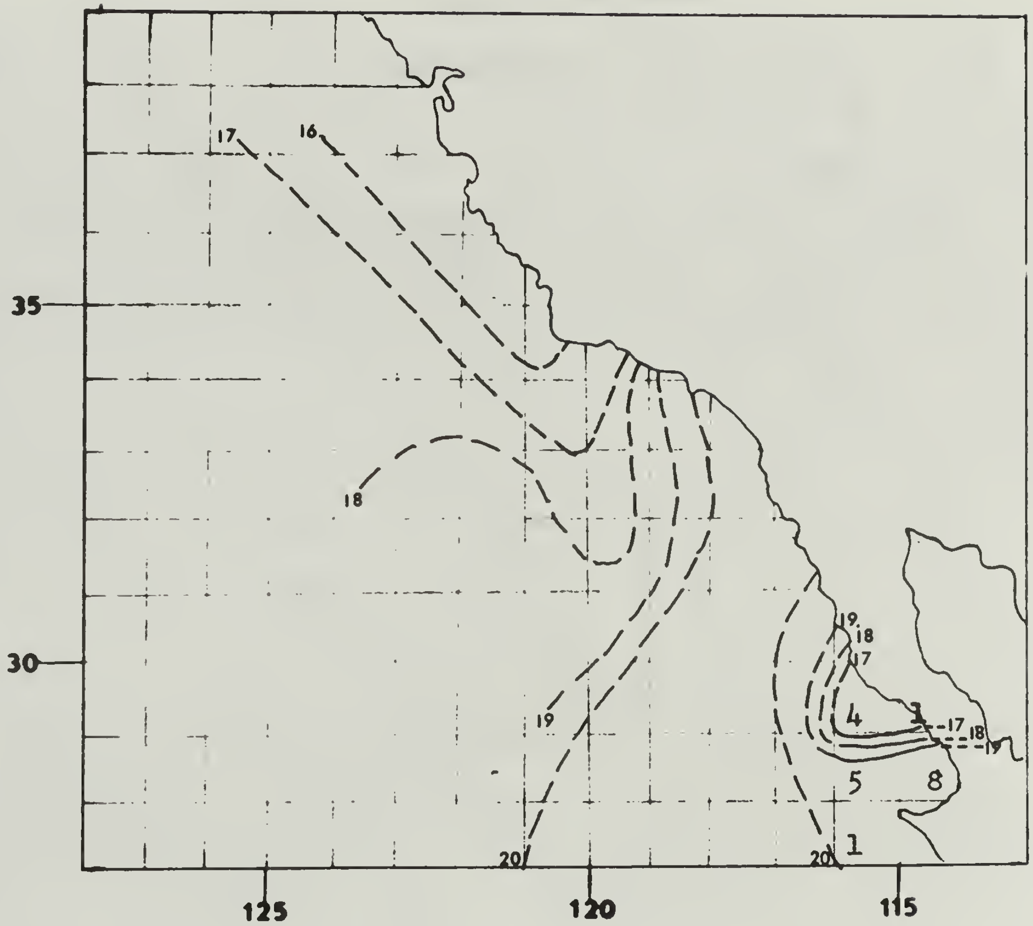
Figure 13c



August 1958

Surface isotherms

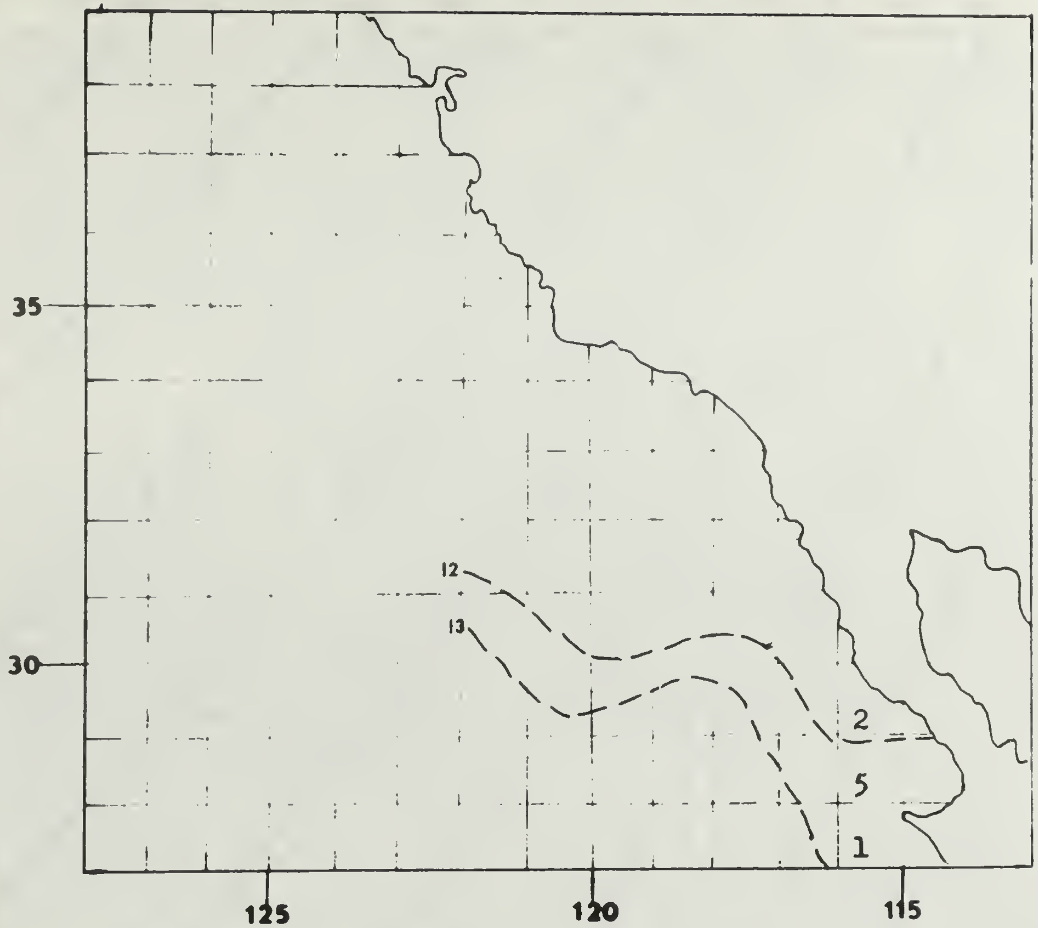
Figure 14a.



August 1958

10-meter level isotherms

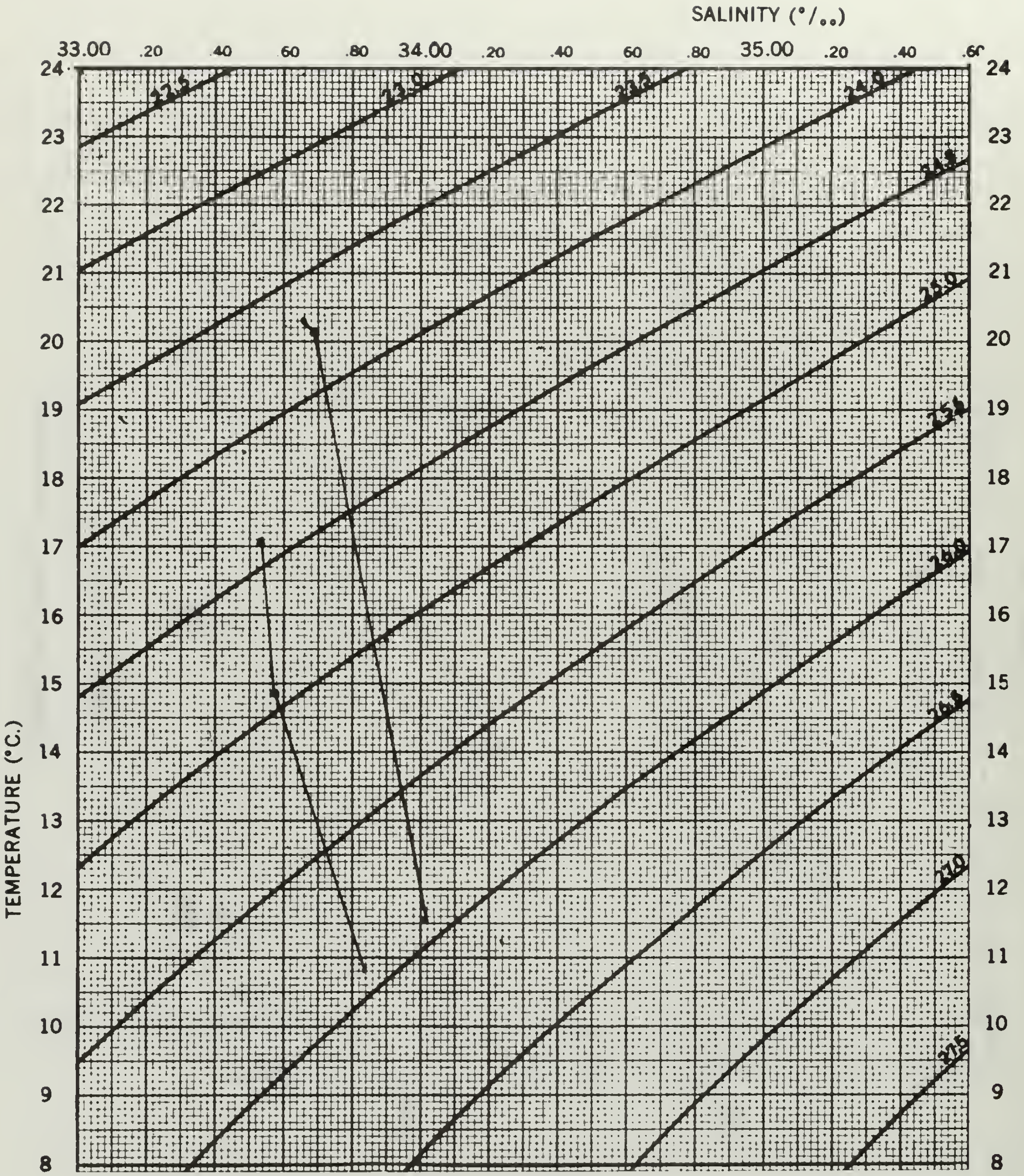
Figure 14b.



August 1958

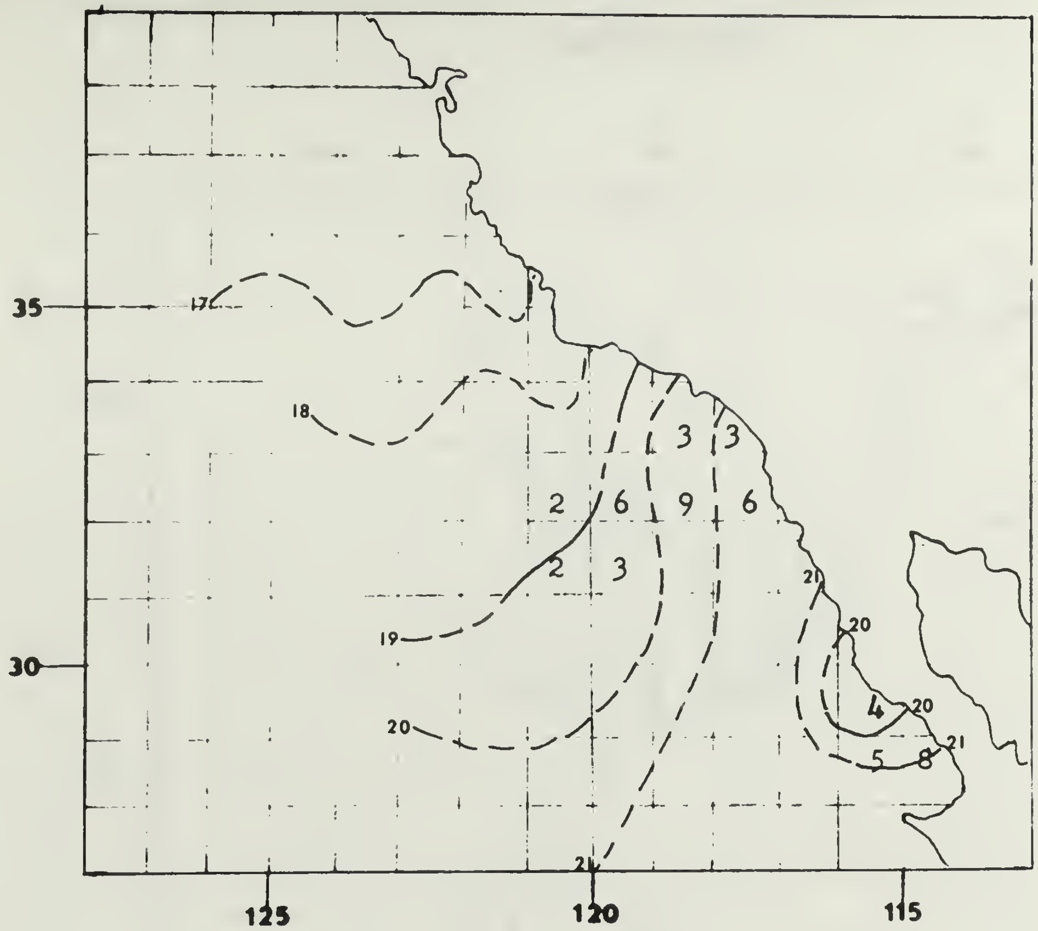
100-meter level isotherms

Figure 14c.



UPWELLING AREA
August 1958
29 N-115 W

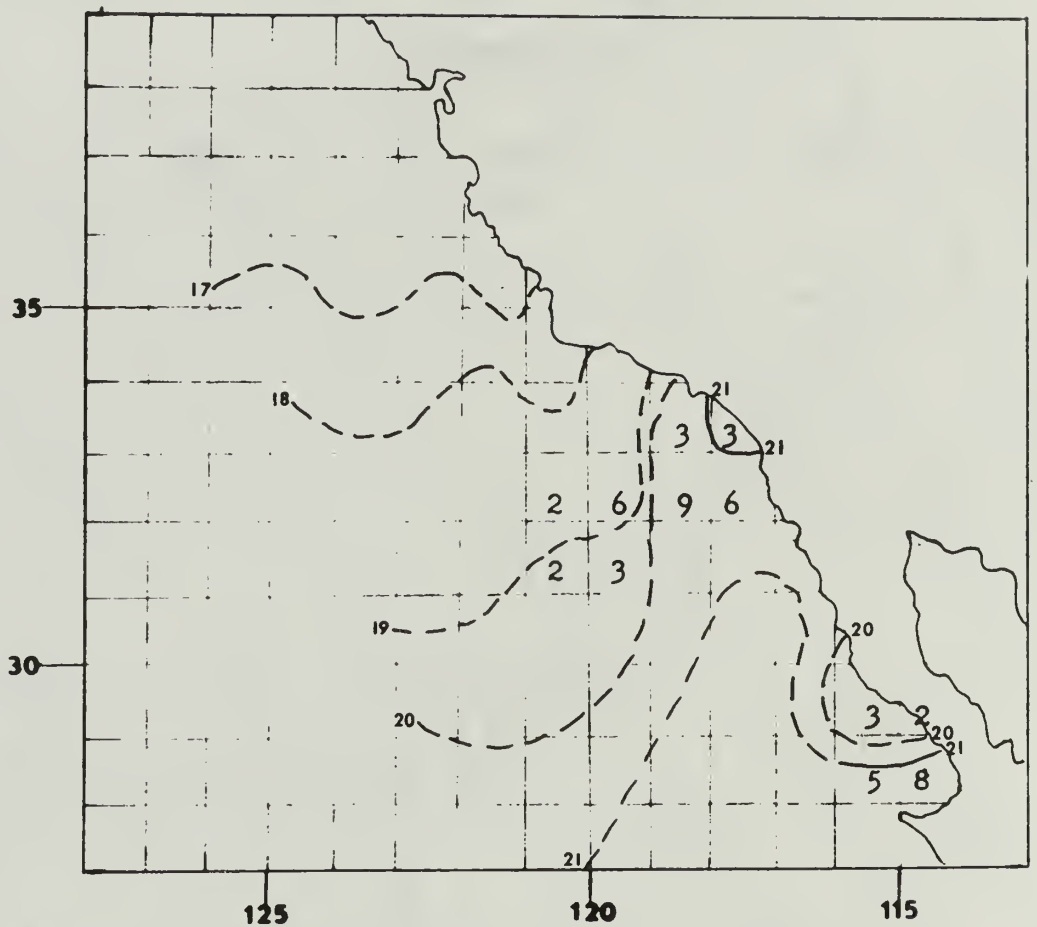
Figure 15a.



September 1958

Surface isotherms

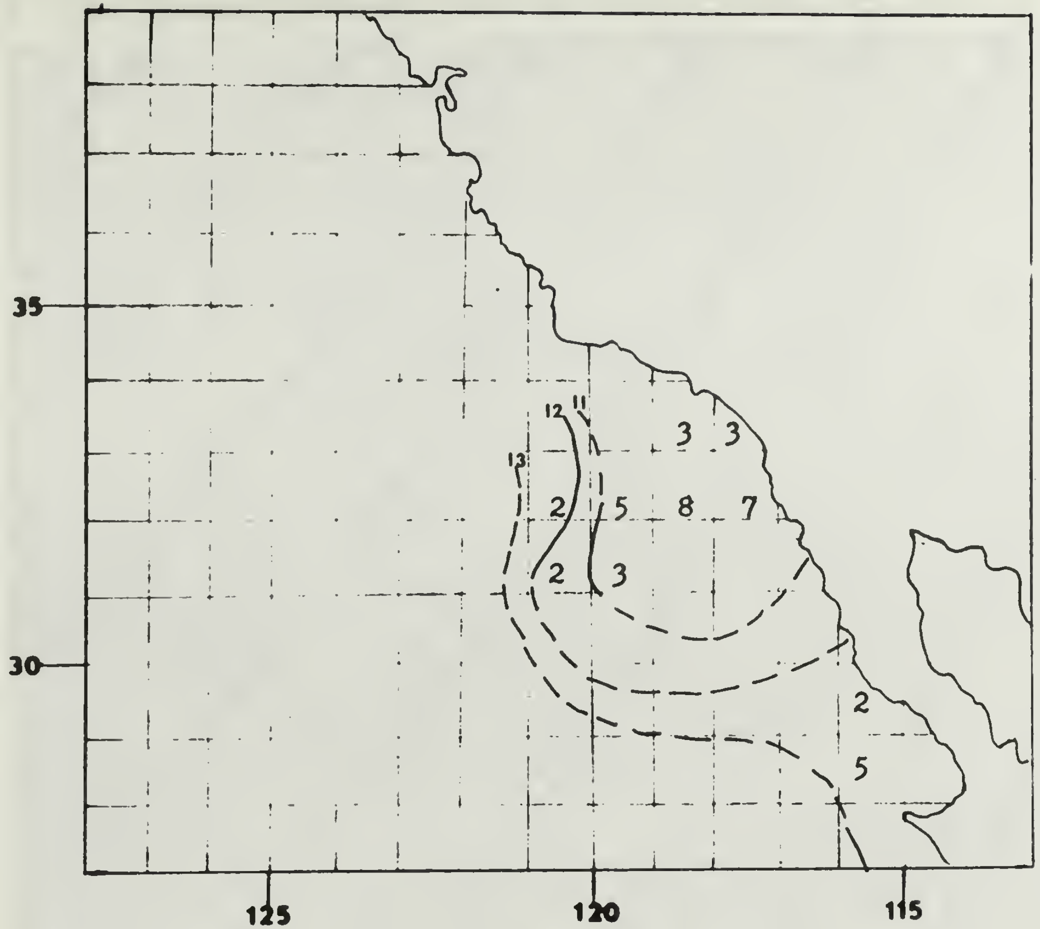
Figure 16a.



September 1958

10-meter level isotherms

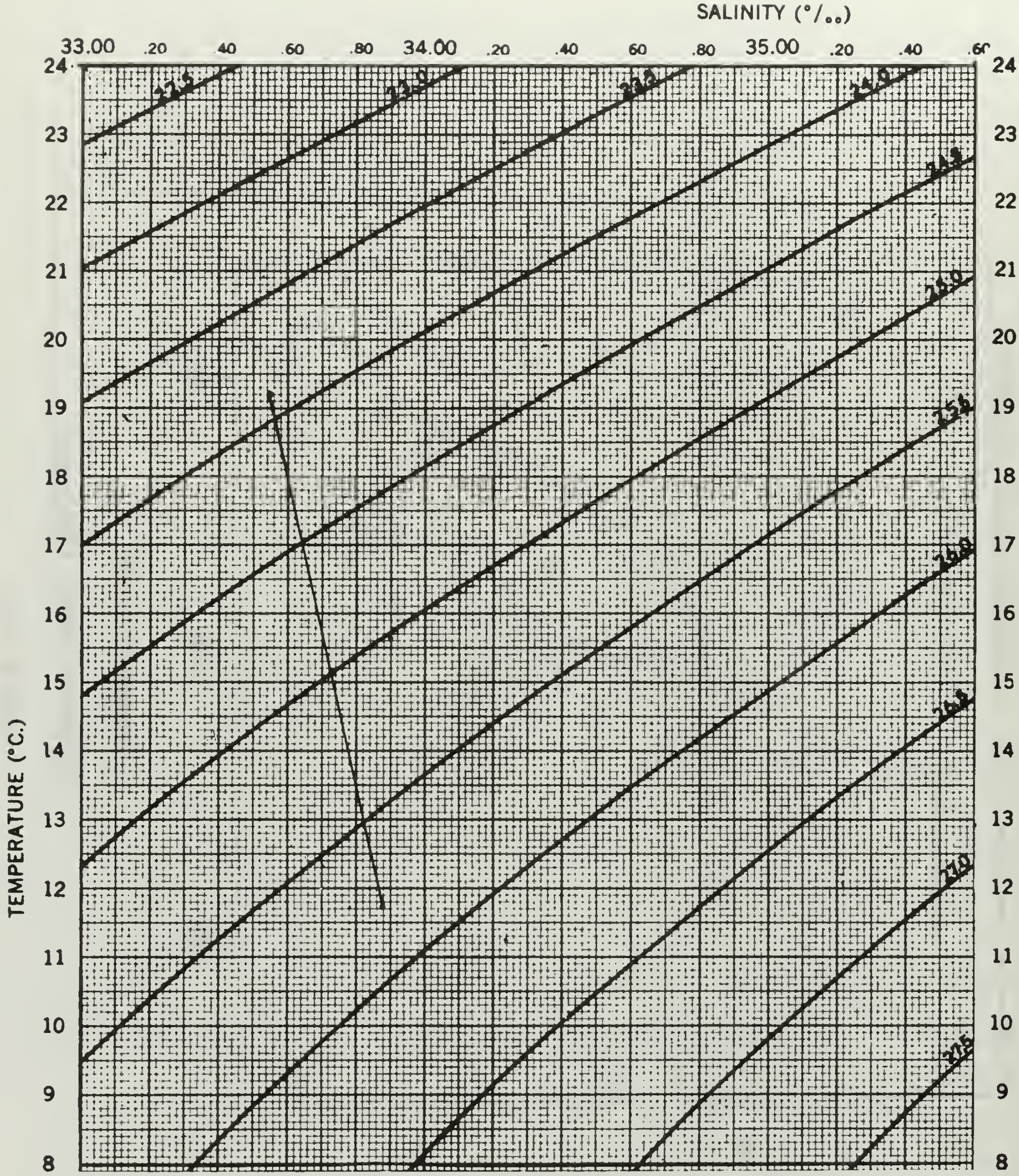
Figure 16b.



September 1958

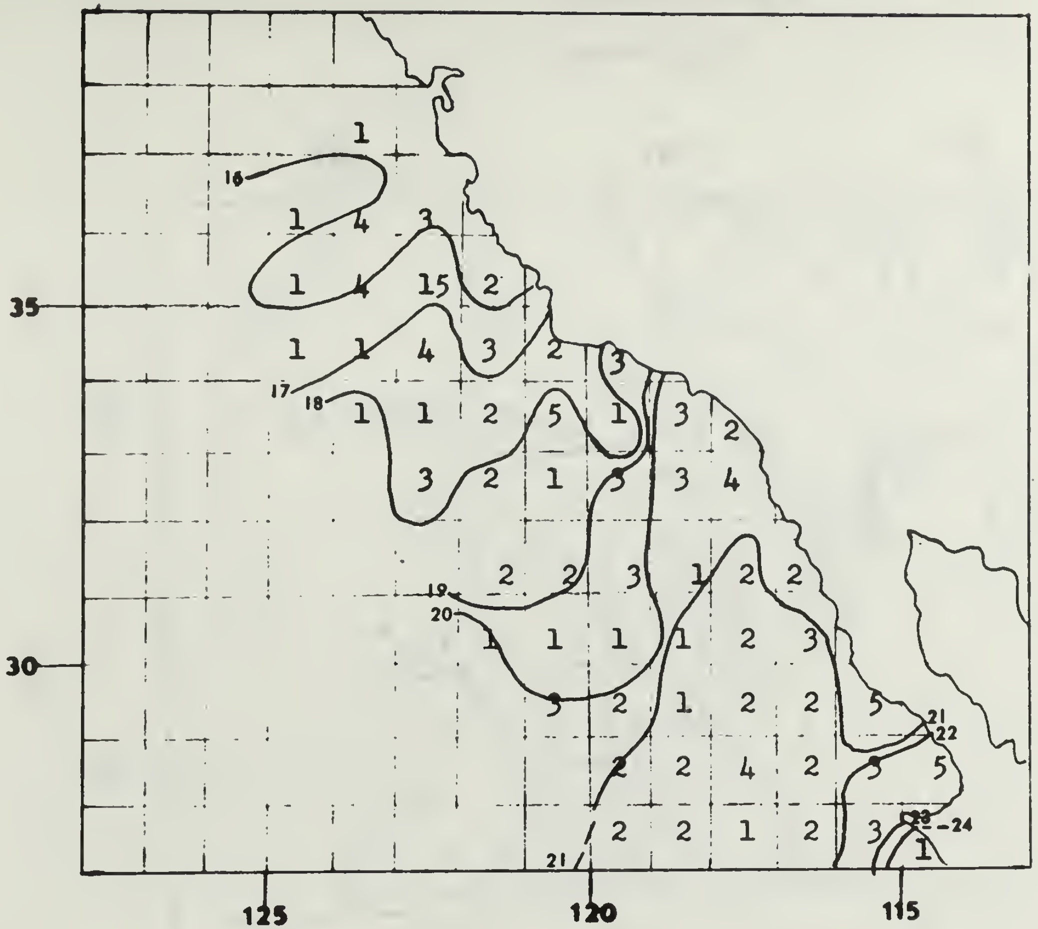
100-meter level isotherms

Figure 16c.



UPWELLING AREA
September 1958
29 N-115 W

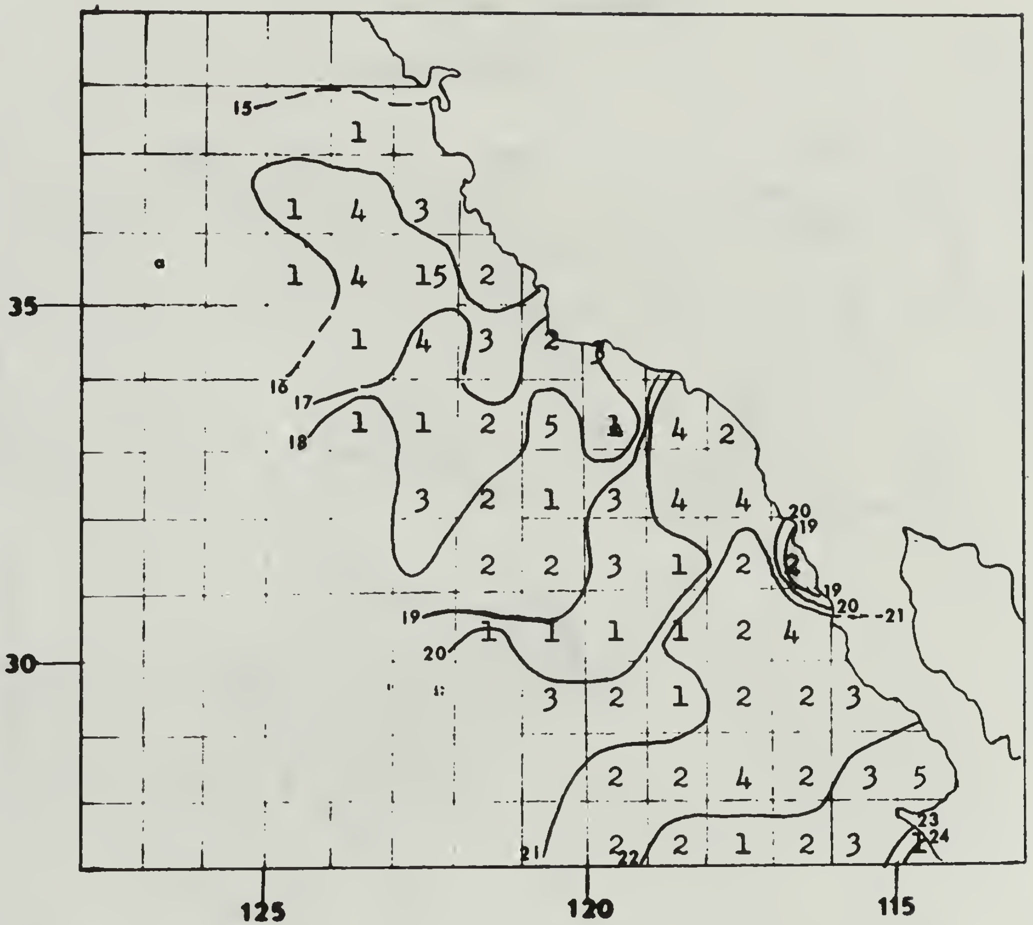
Figure 17a.



October 1958

Surface isotherms

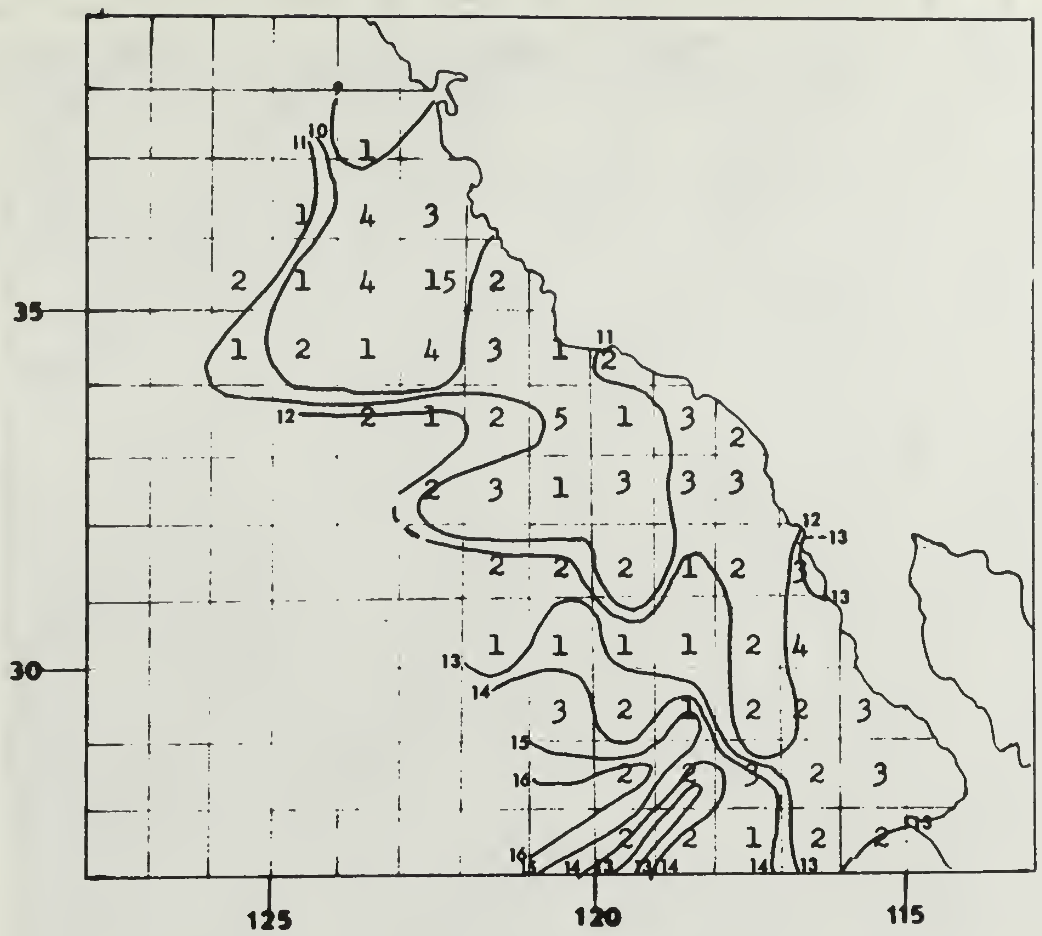
Figure 18a.



October 1958

10-meter level isotherms

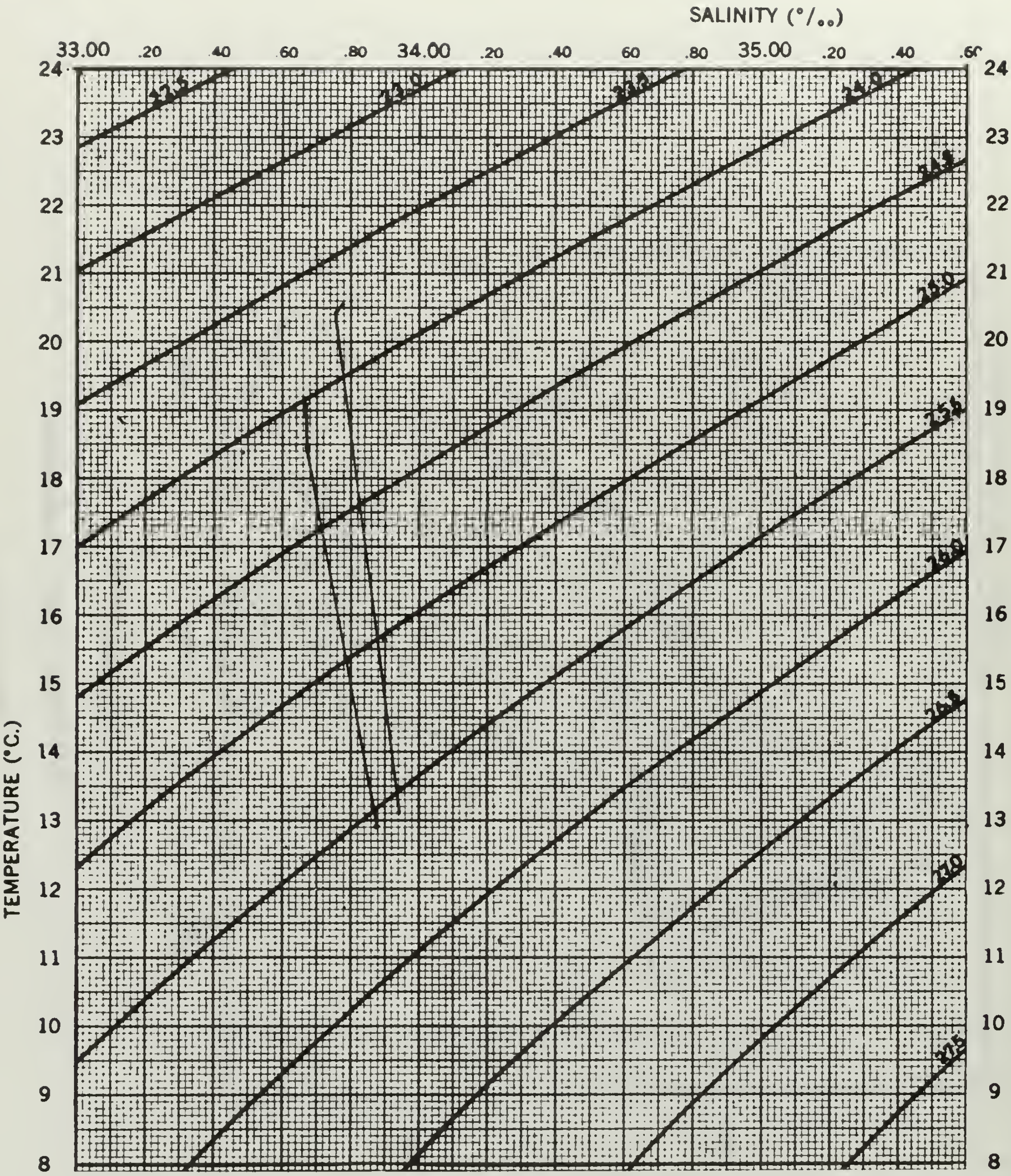
Figure 18b.



October 1958

100-meter level isotherms

Figure 18c.

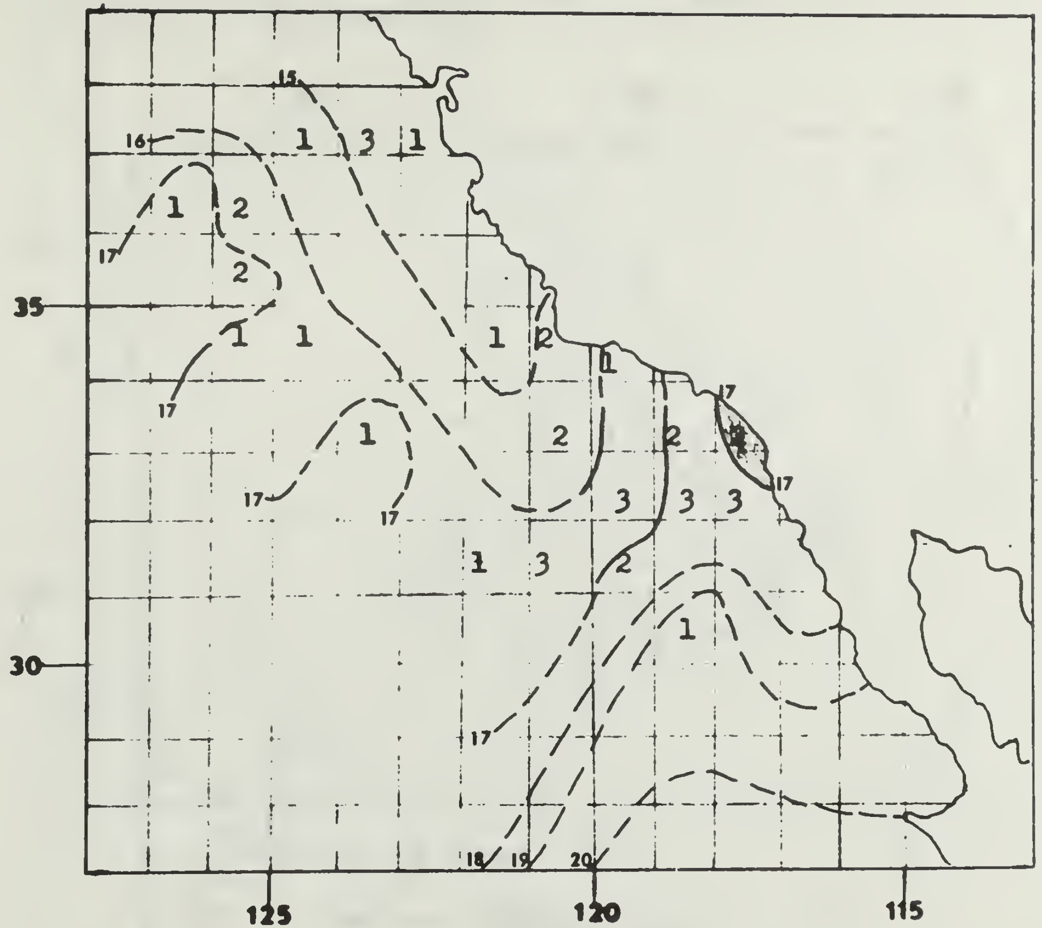


UPWELLING AREA

October 1958

31 N-116 W

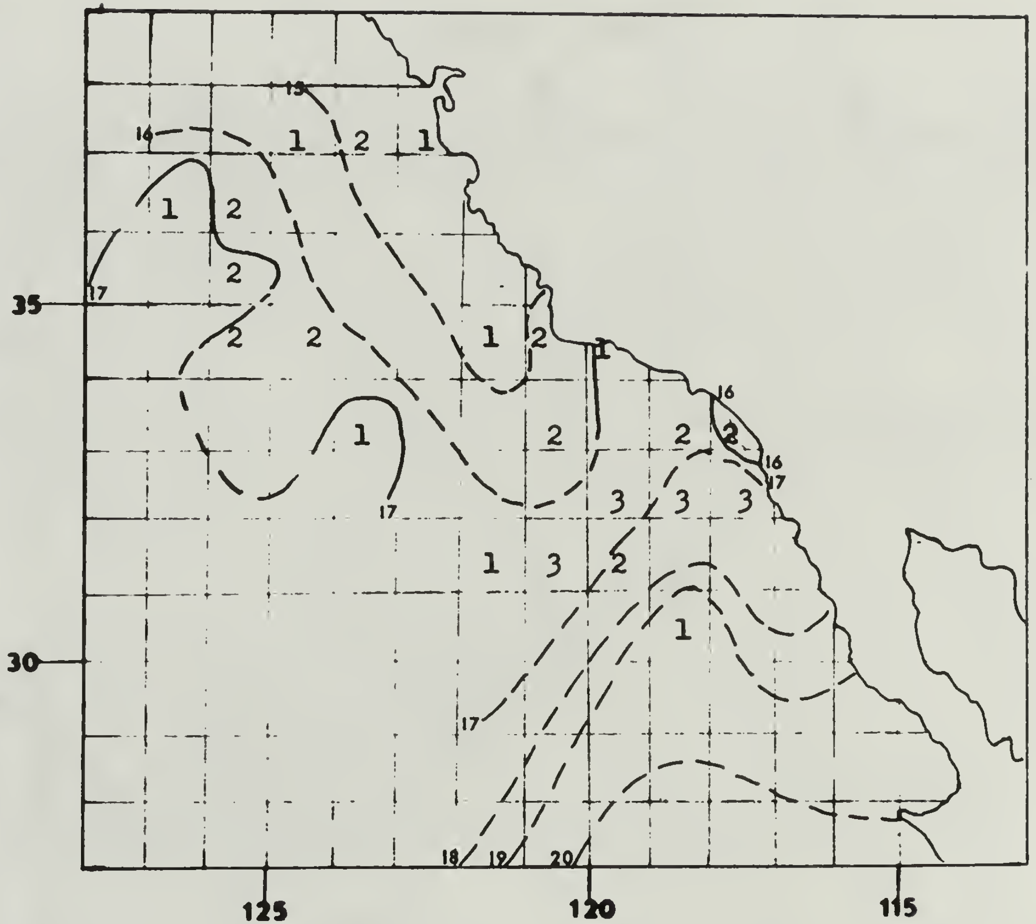
Figure 19a



November 1958

Surface isotherms

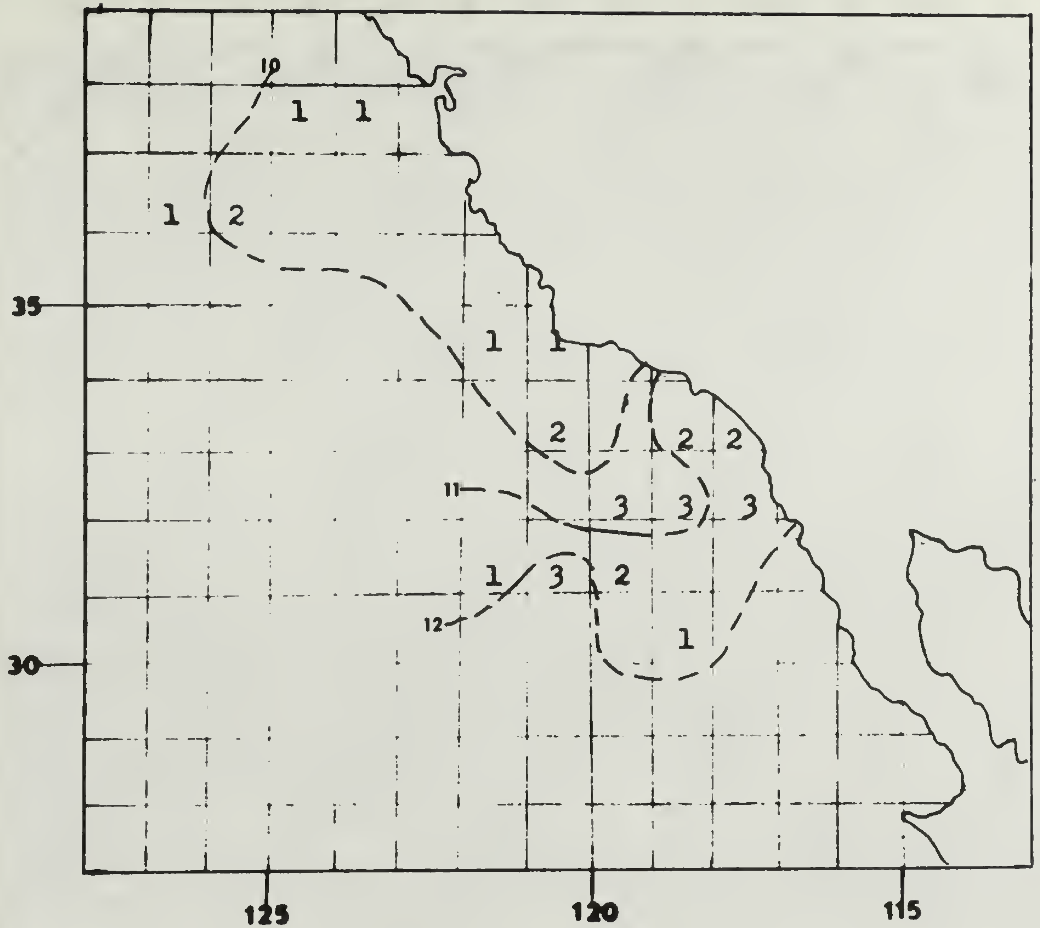
Figure 20a.



November 1958

10-meter level isotherms

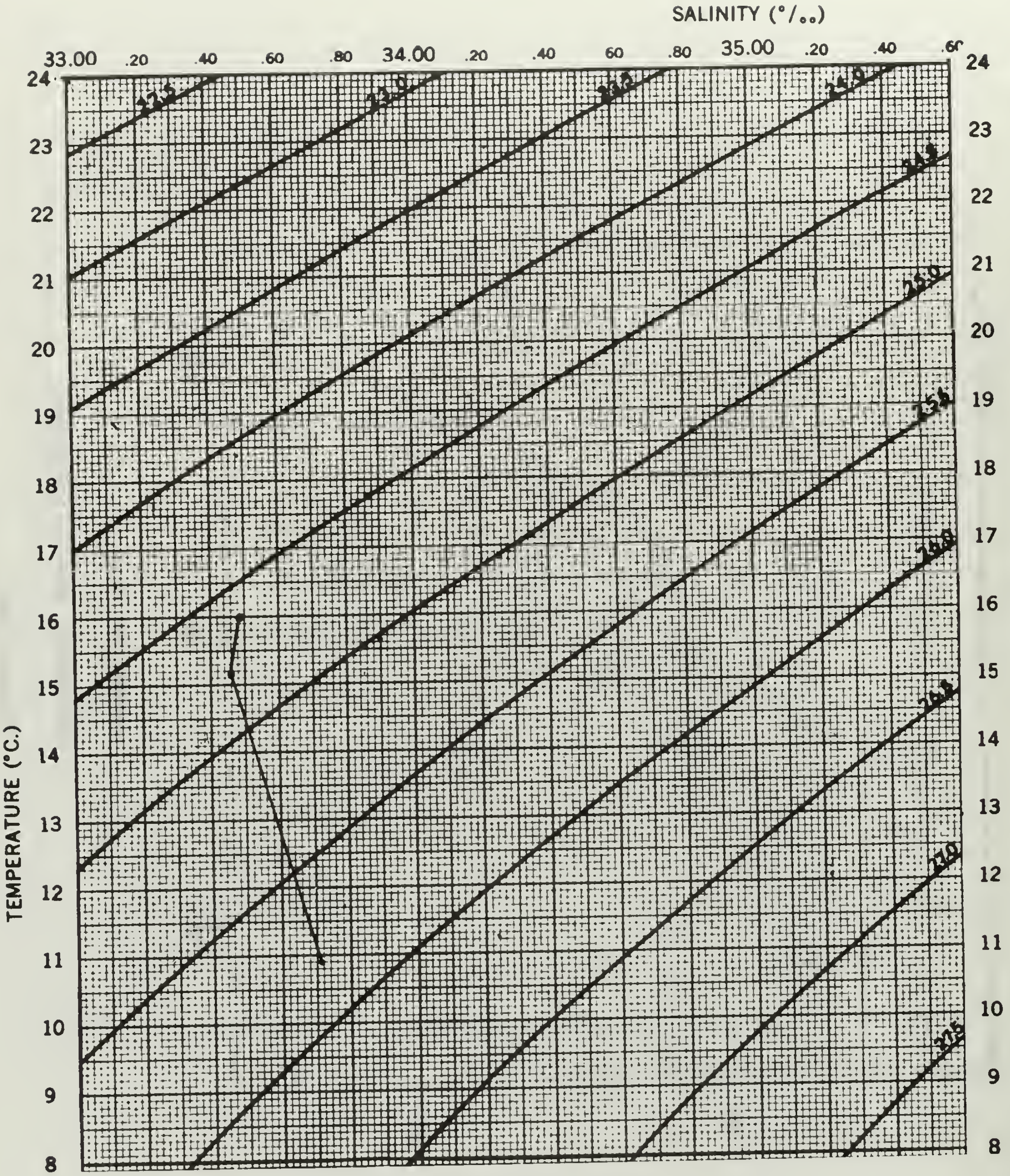
Figure 20b.



November 1958

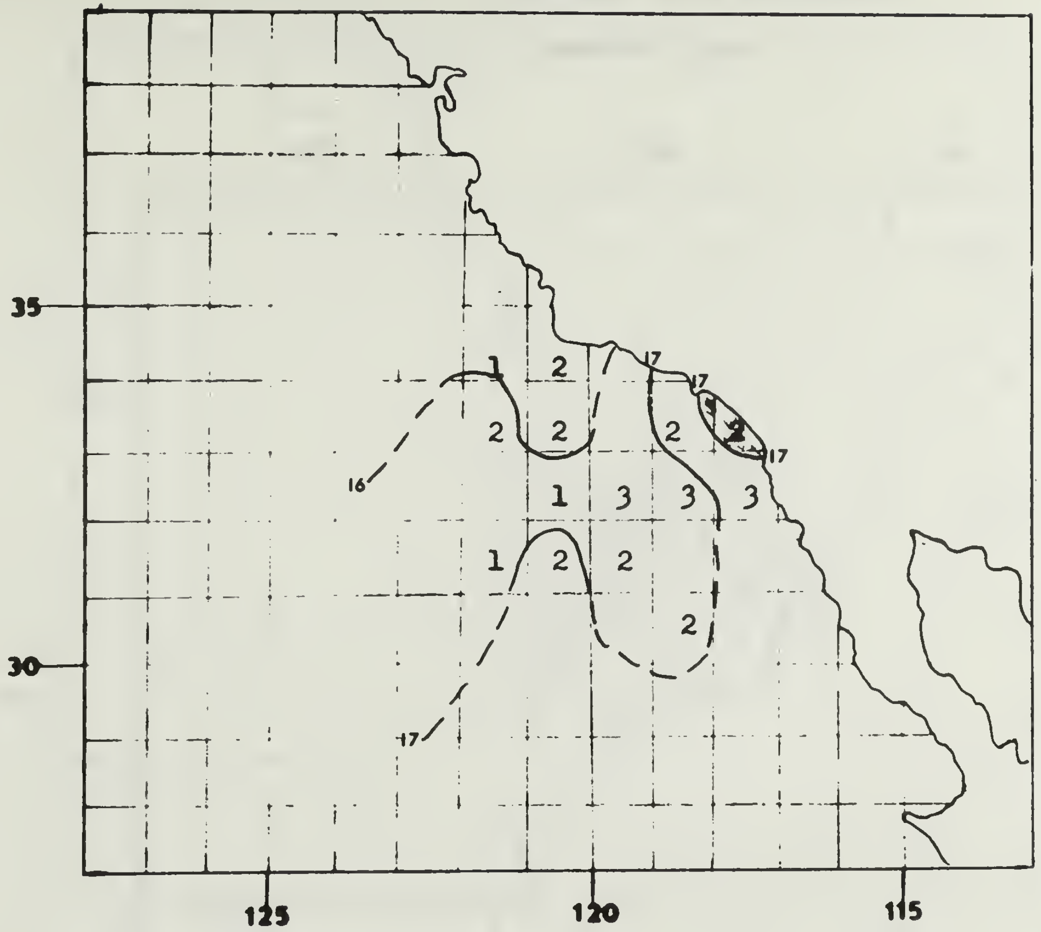
100-meter level isotherms

Figure 20c.



UPWELLING AREA
November 1958
33 N-117 W

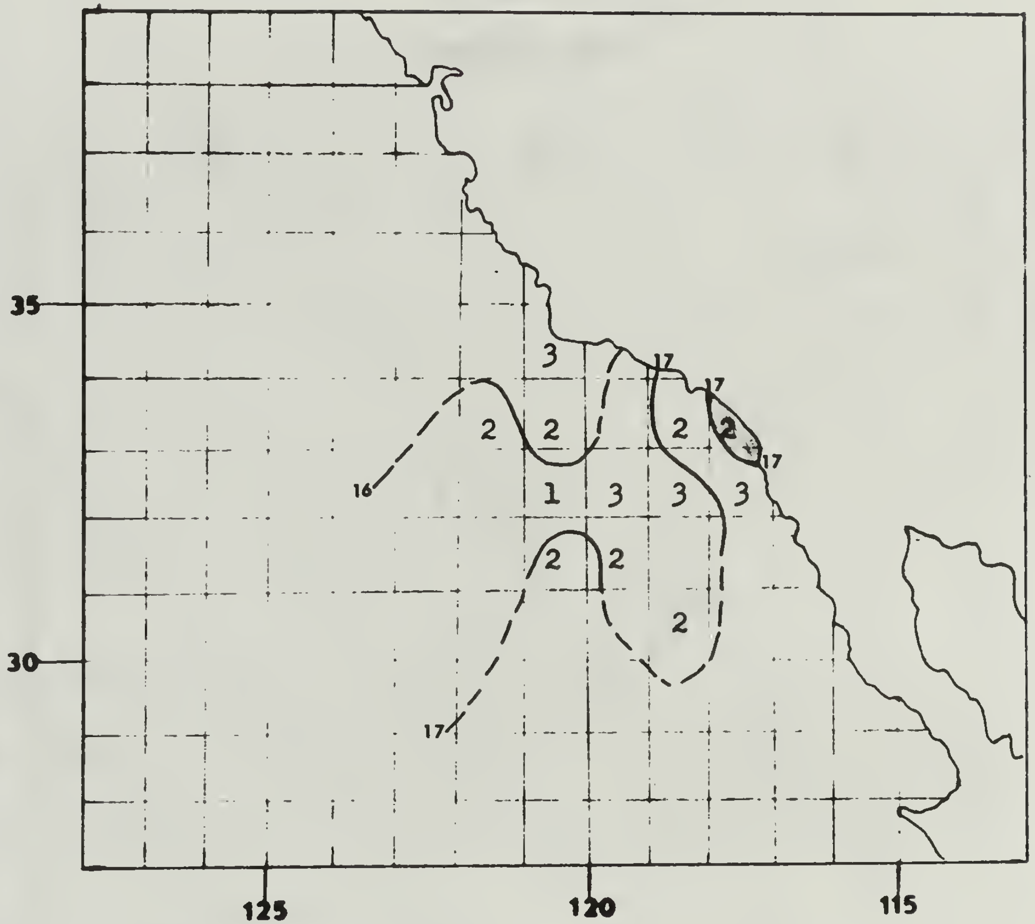
Figure 21a.



December 1958

Surface isotherms

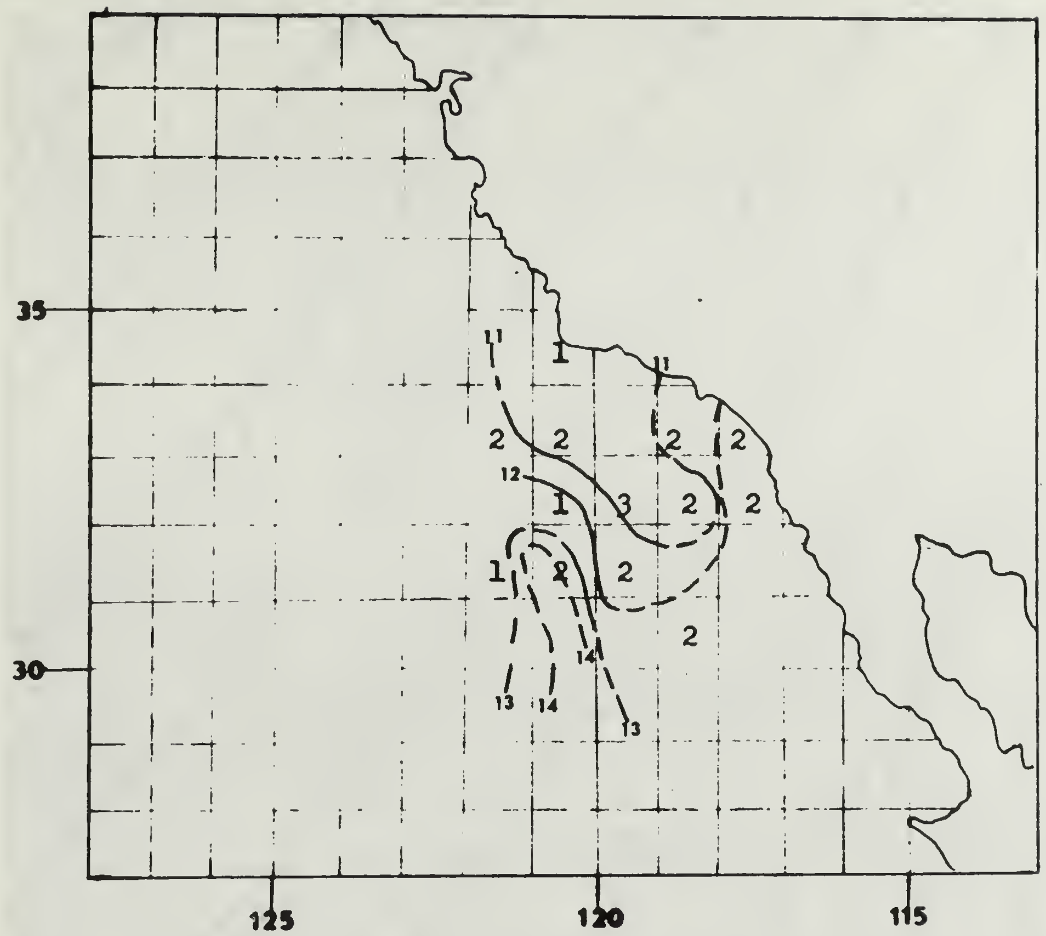
Figure 22a.



December 1958

10-meter level isotherms

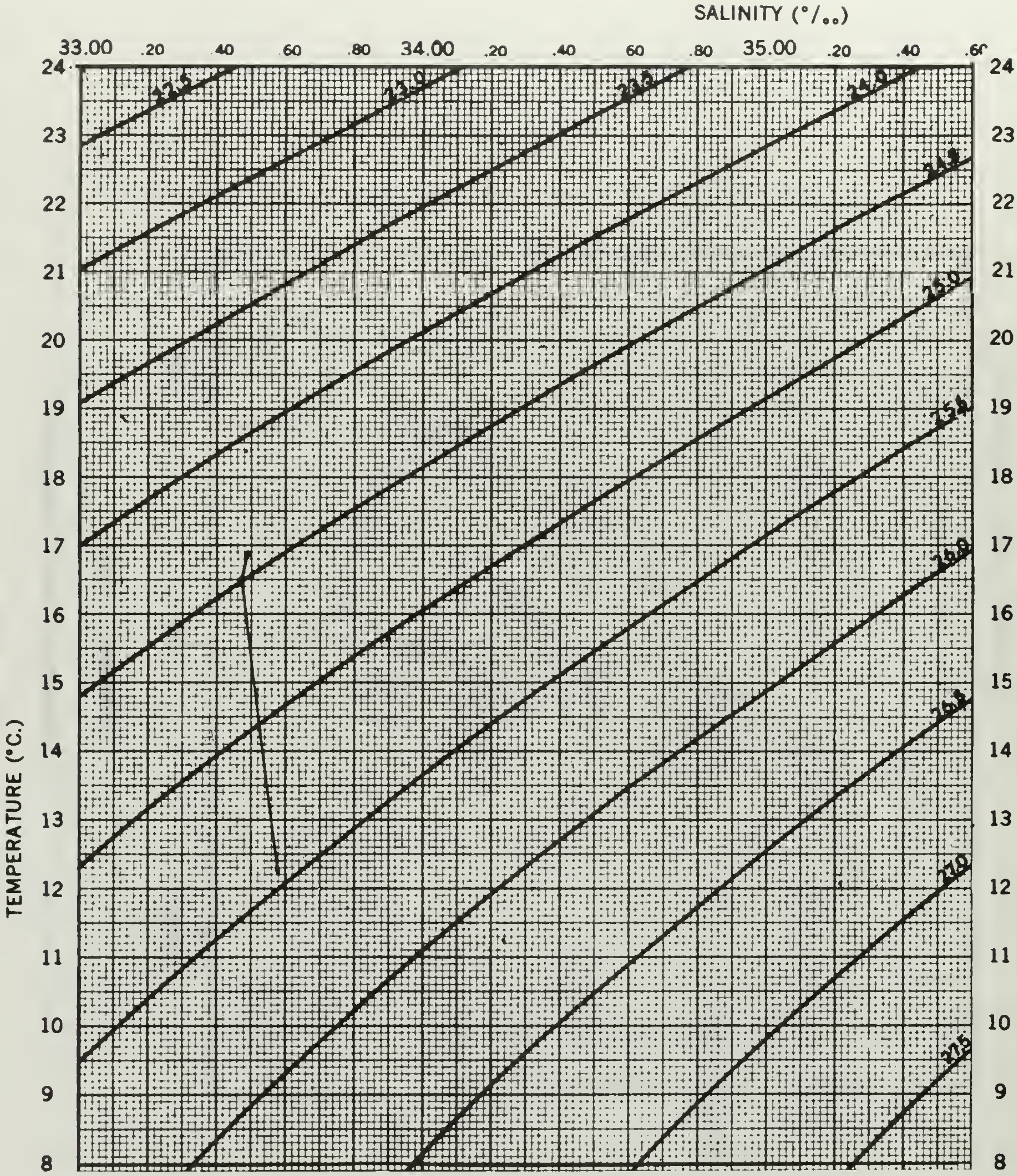
Figure 22b.



December 1958

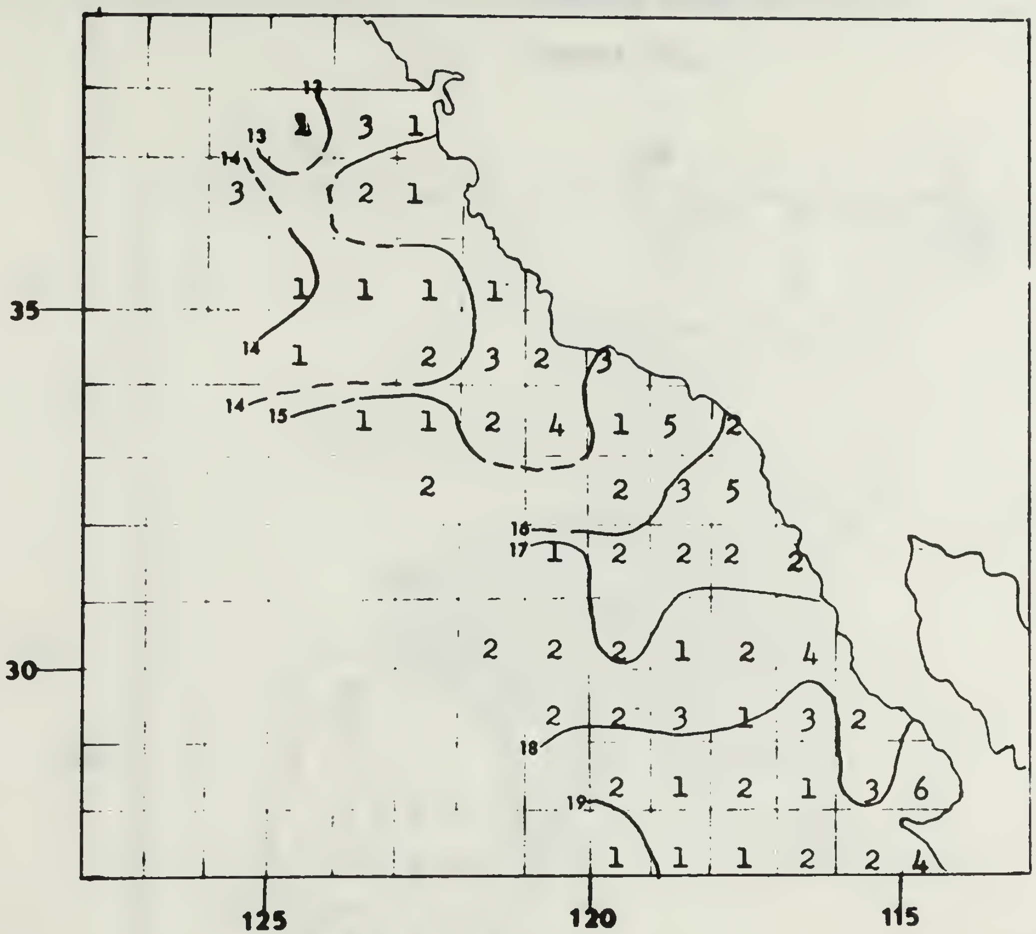
100-meter level isotherms

Figure 22e.



UPWELLING AREA
December 1958
33 N-117 W

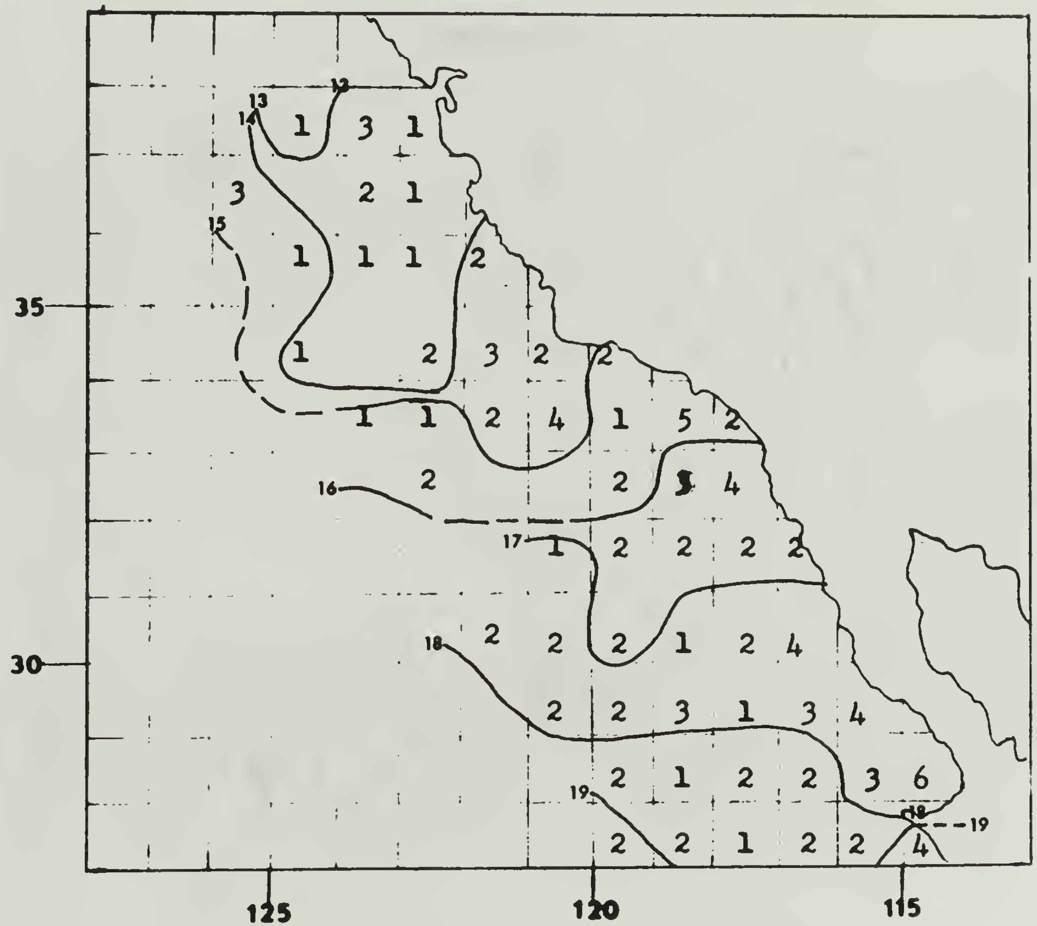
Figure 23a.



January 1959

Surface isotherms

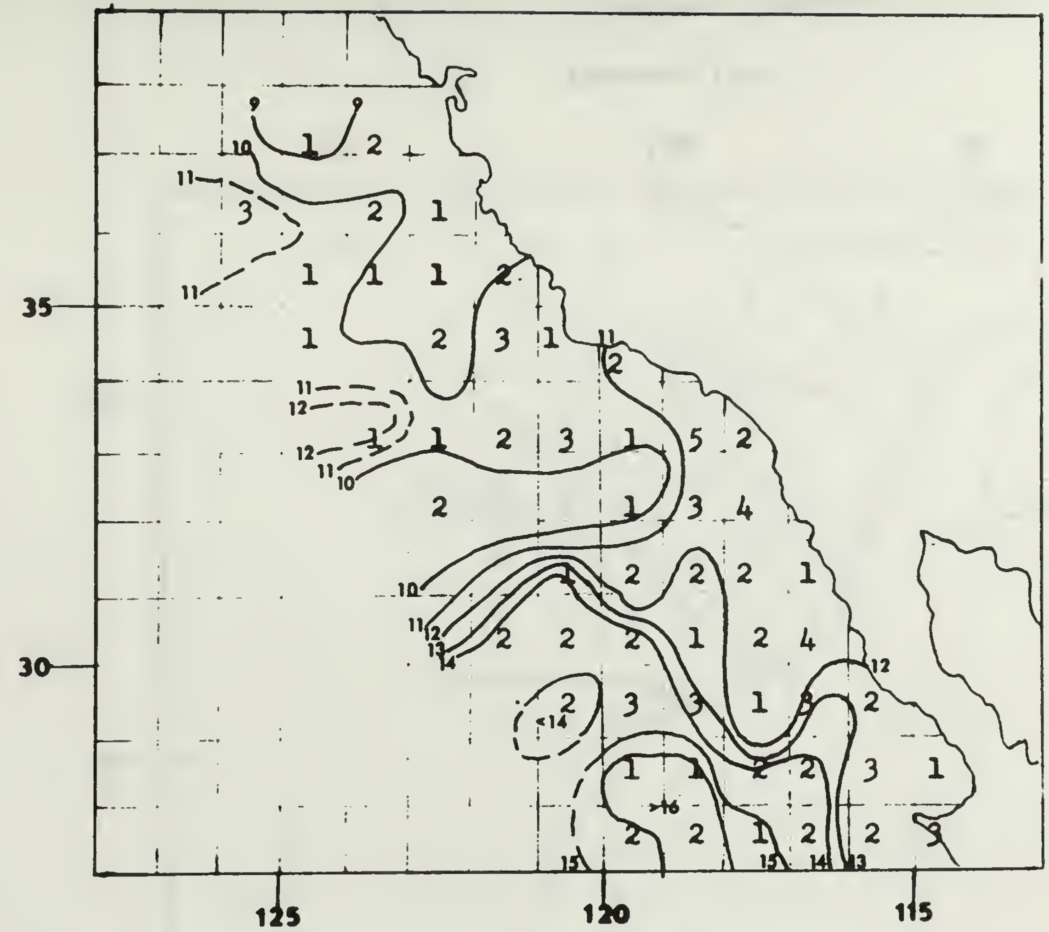
Figure 24a.



January 1959

10-meter level isotherms

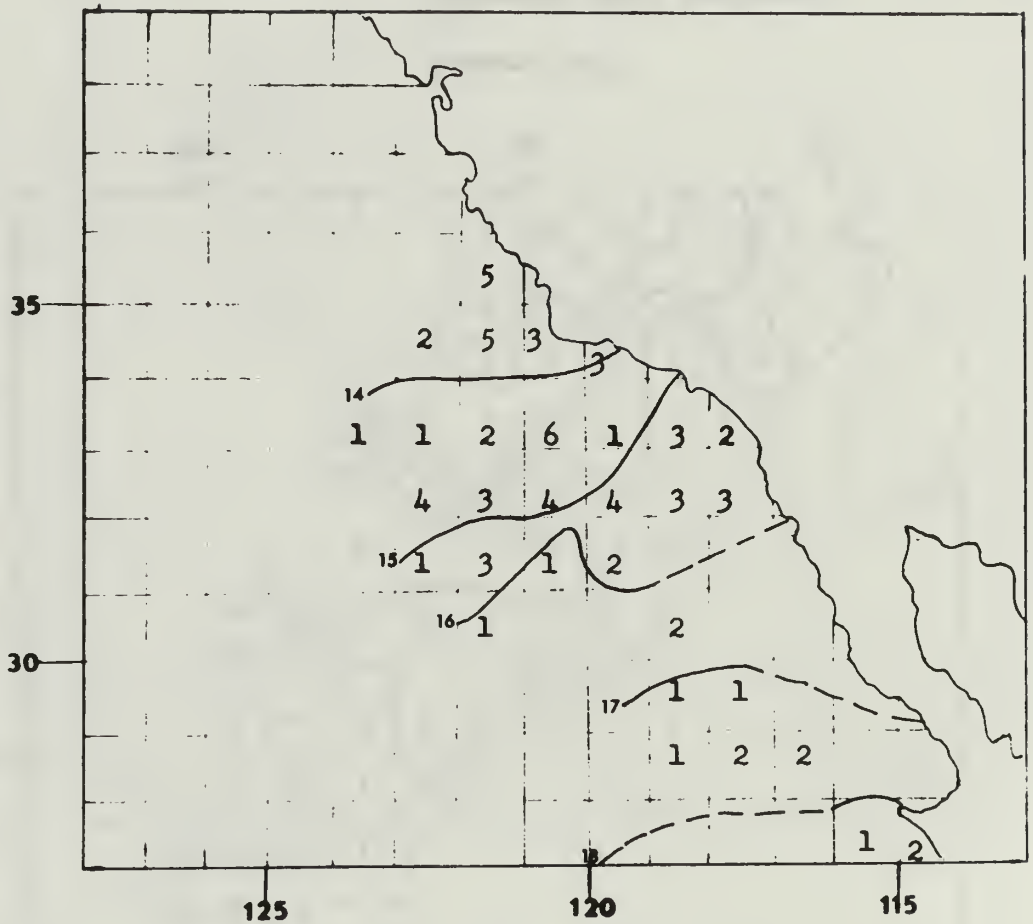
Figure 24b.



January 1959

100-meter level isotherms

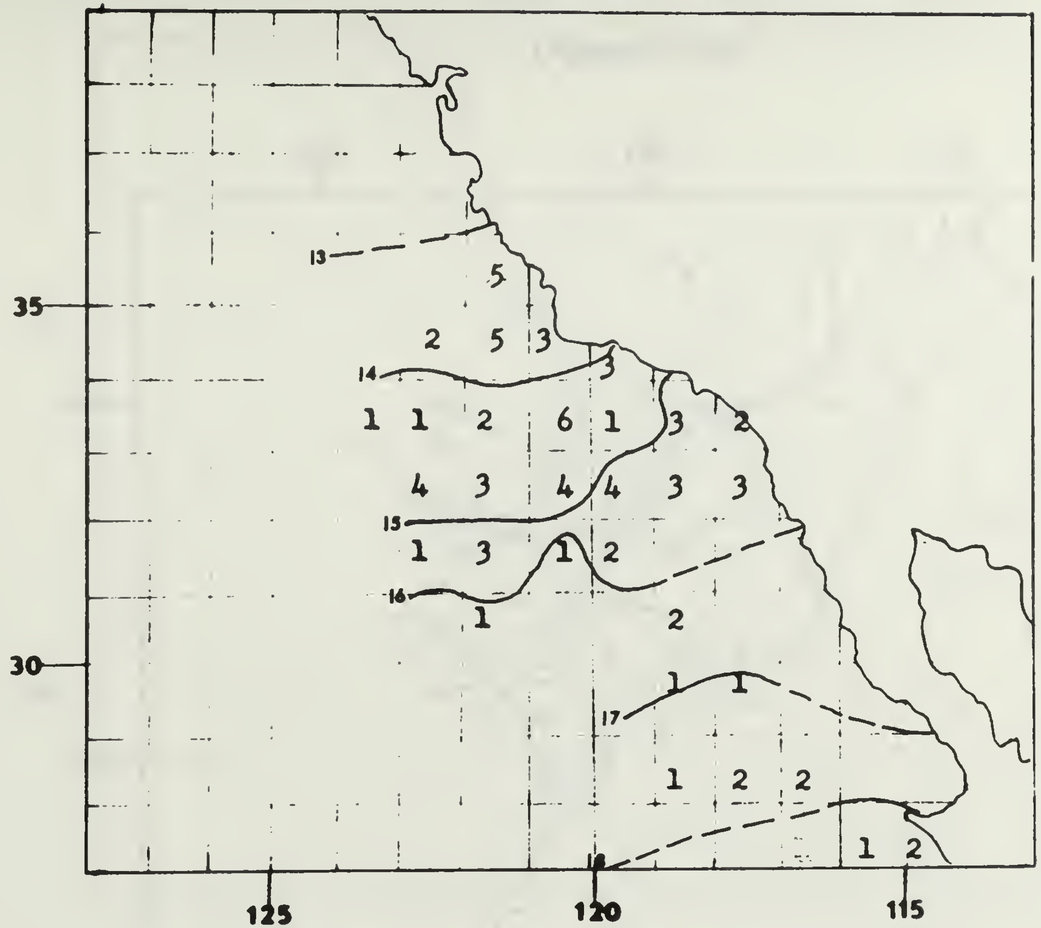
Figure 24c.



February 1959

Surface isotherms

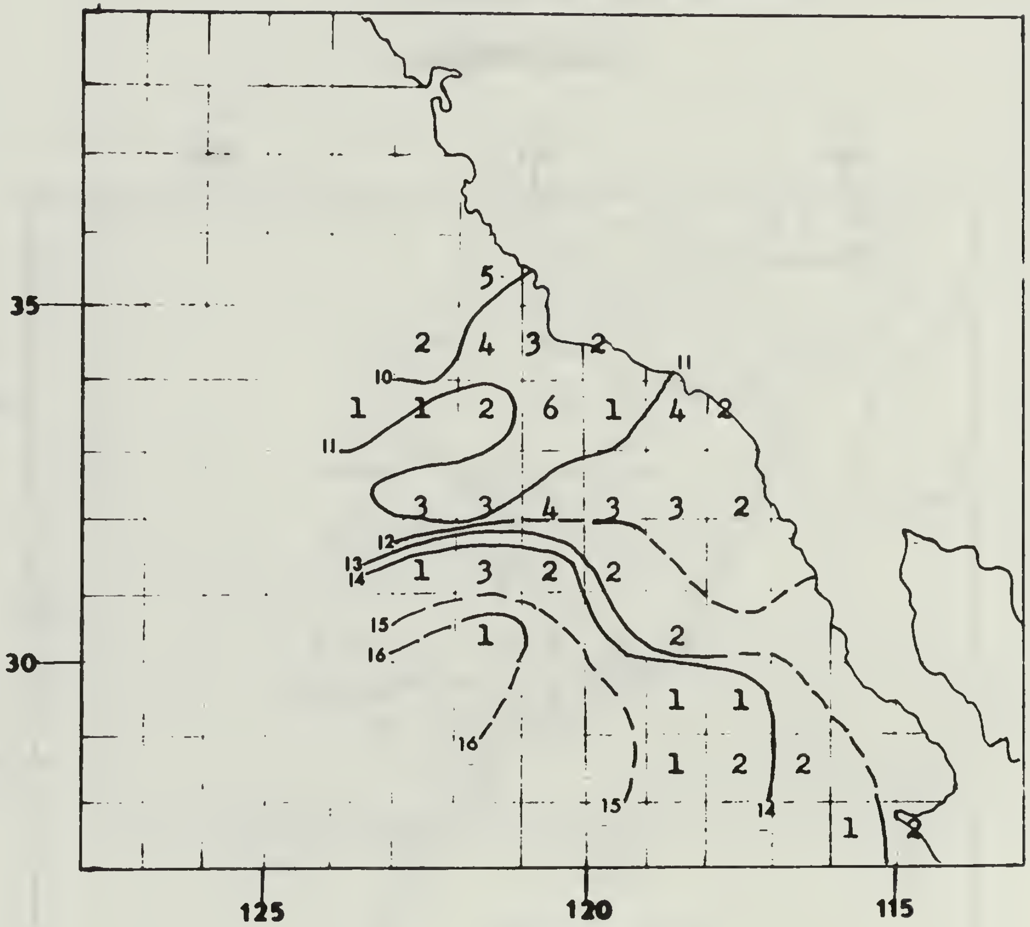
Figure 25a.



February 1959

10-meter level isotherms

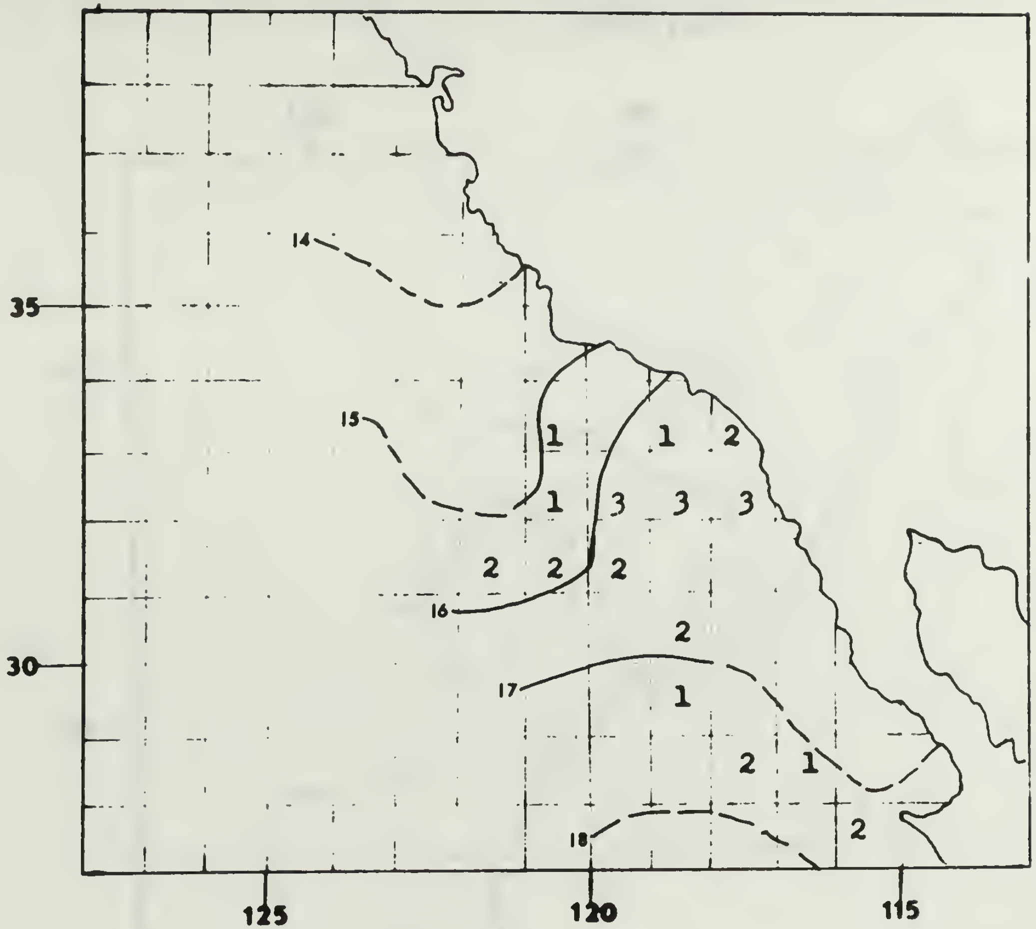
Figure 25b.



February 1959

100-meter level isotherms

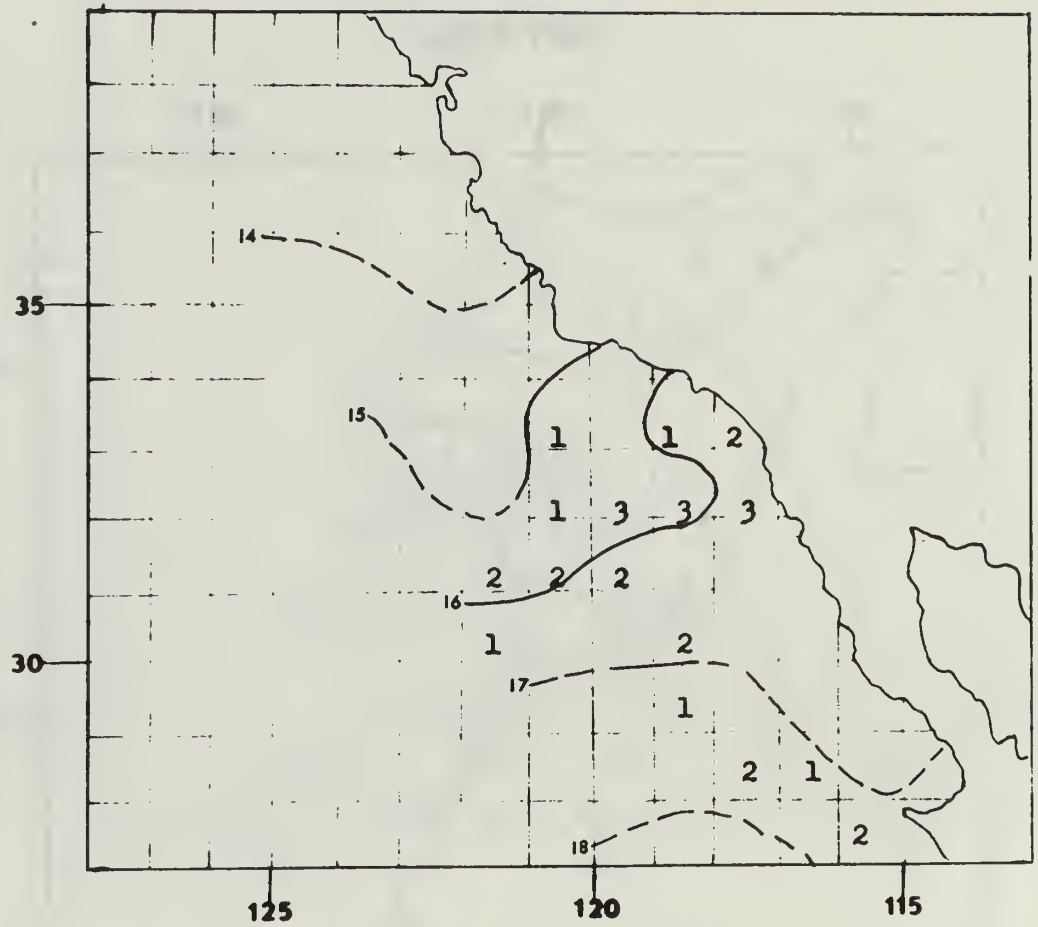
Figure 25e.



March 1959

Surface isotherms

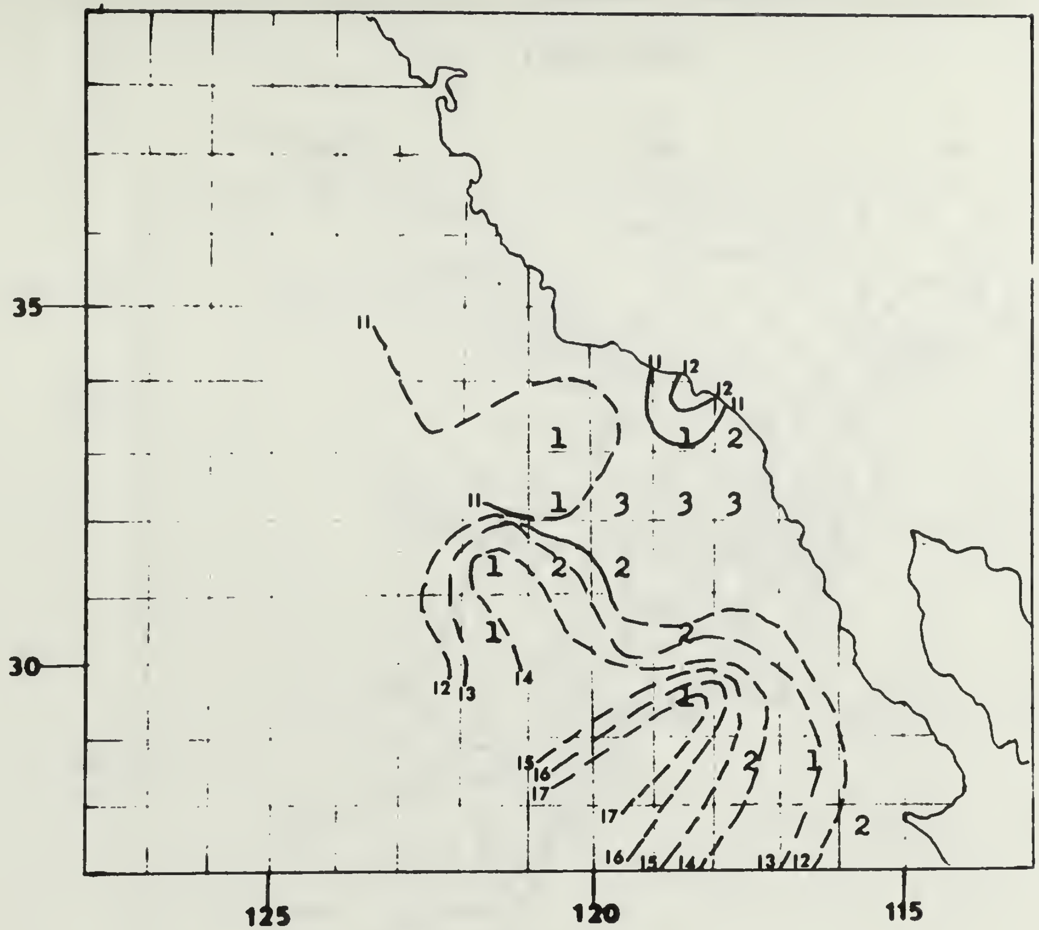
Figure 26a.



March 1959

10-meter level isotherms

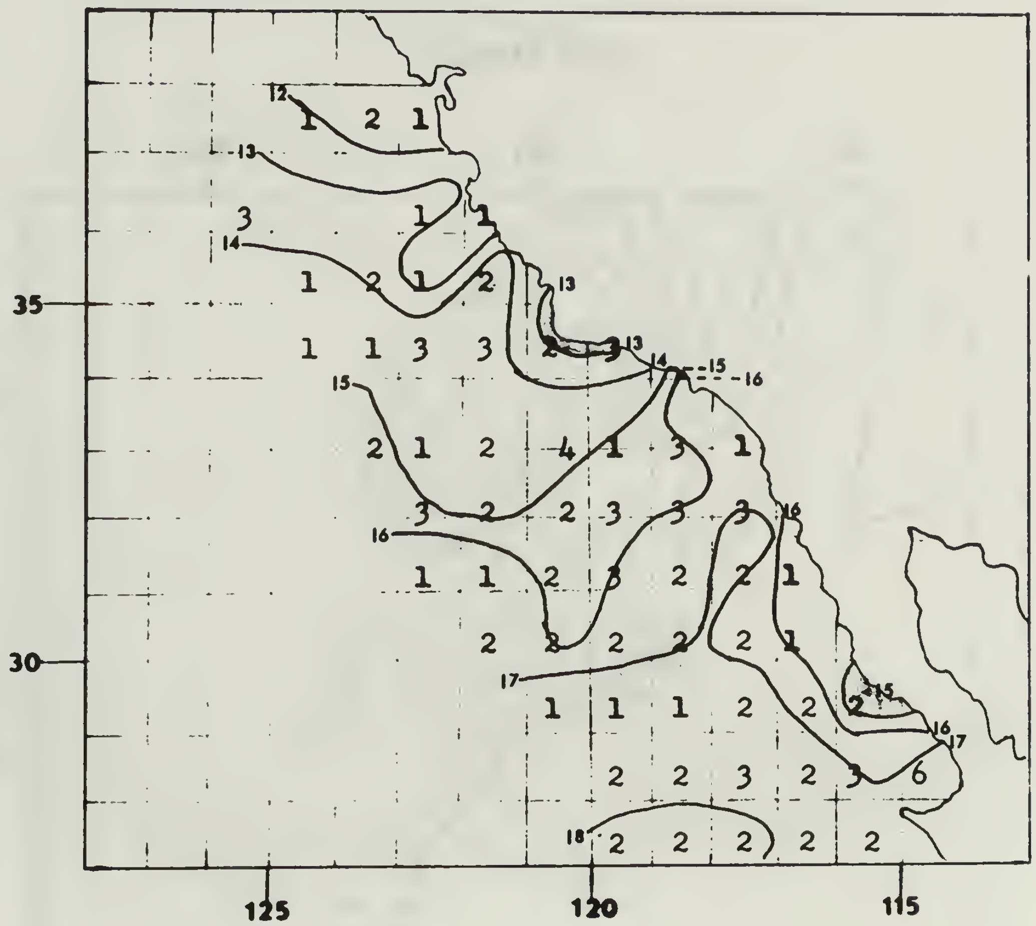
Figure 26b.



March 1959

100-meter level isotherms

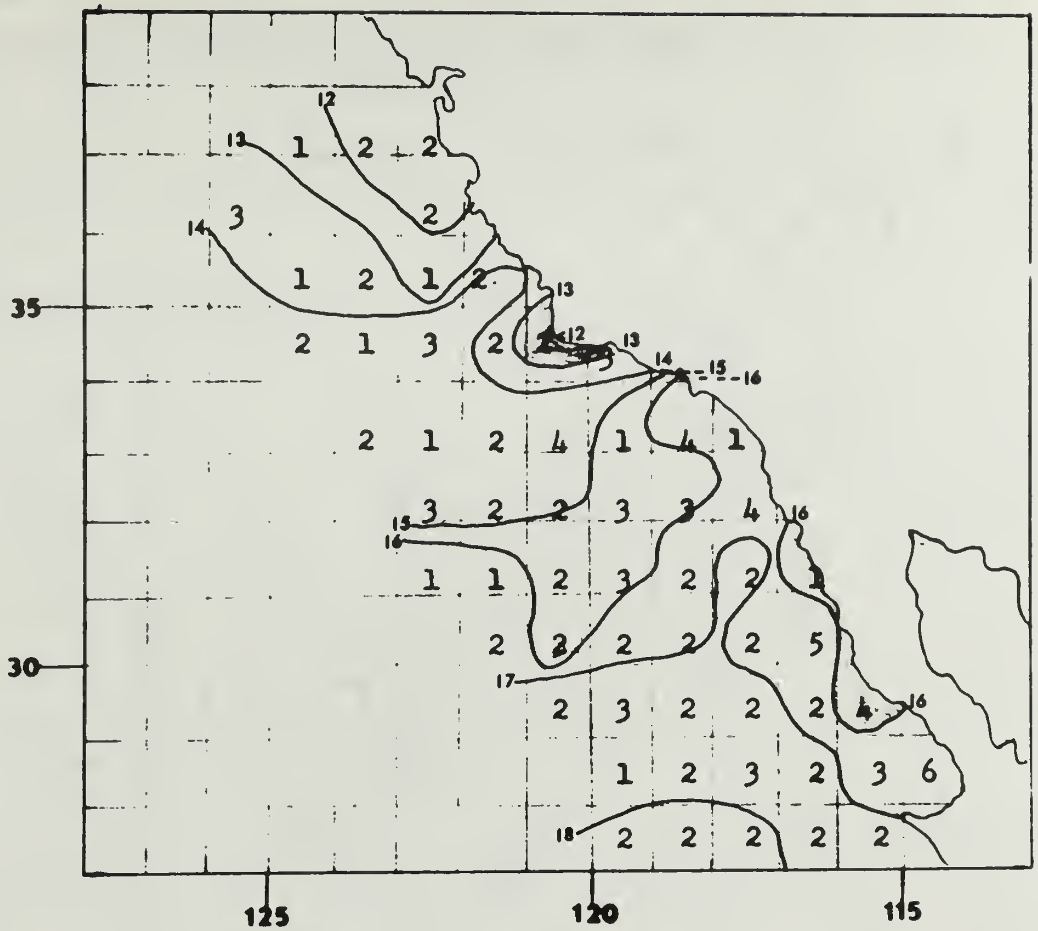
Figure 26c.



April 1959

Surface isotherms

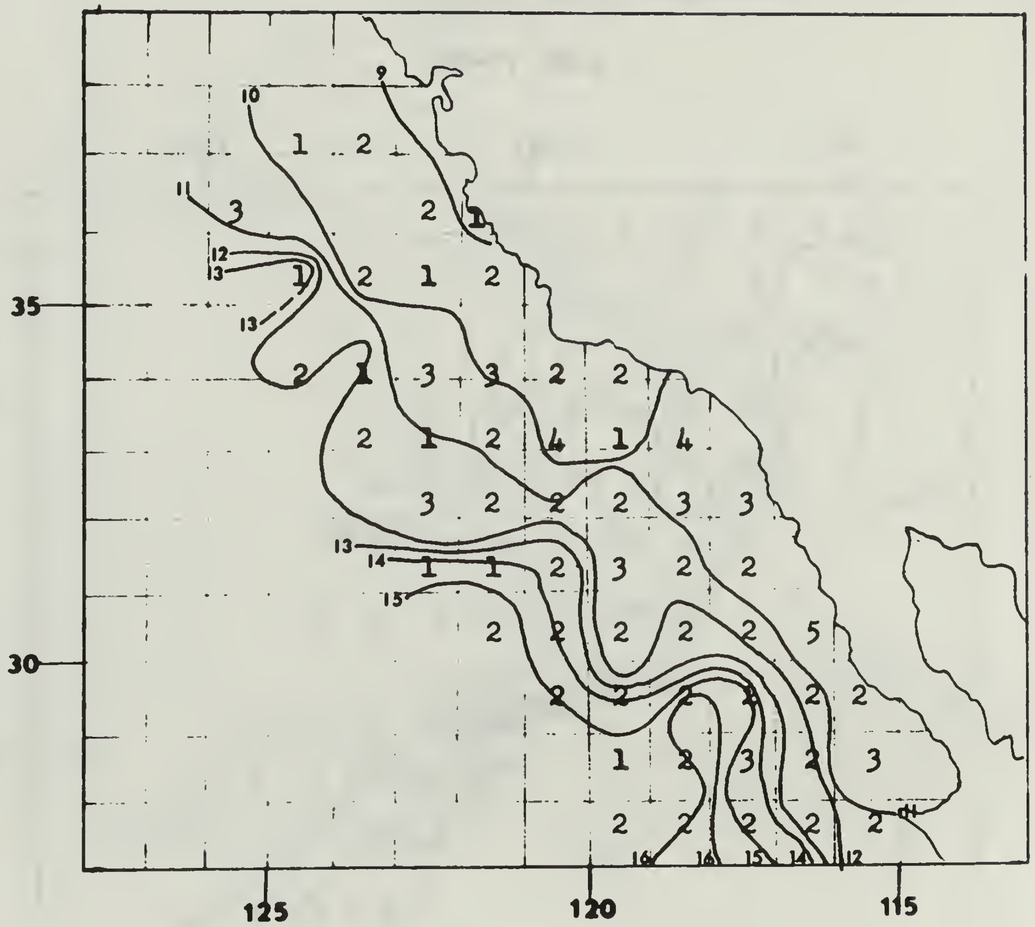
Figure 27a.



April 1959

10-meter level isotherms

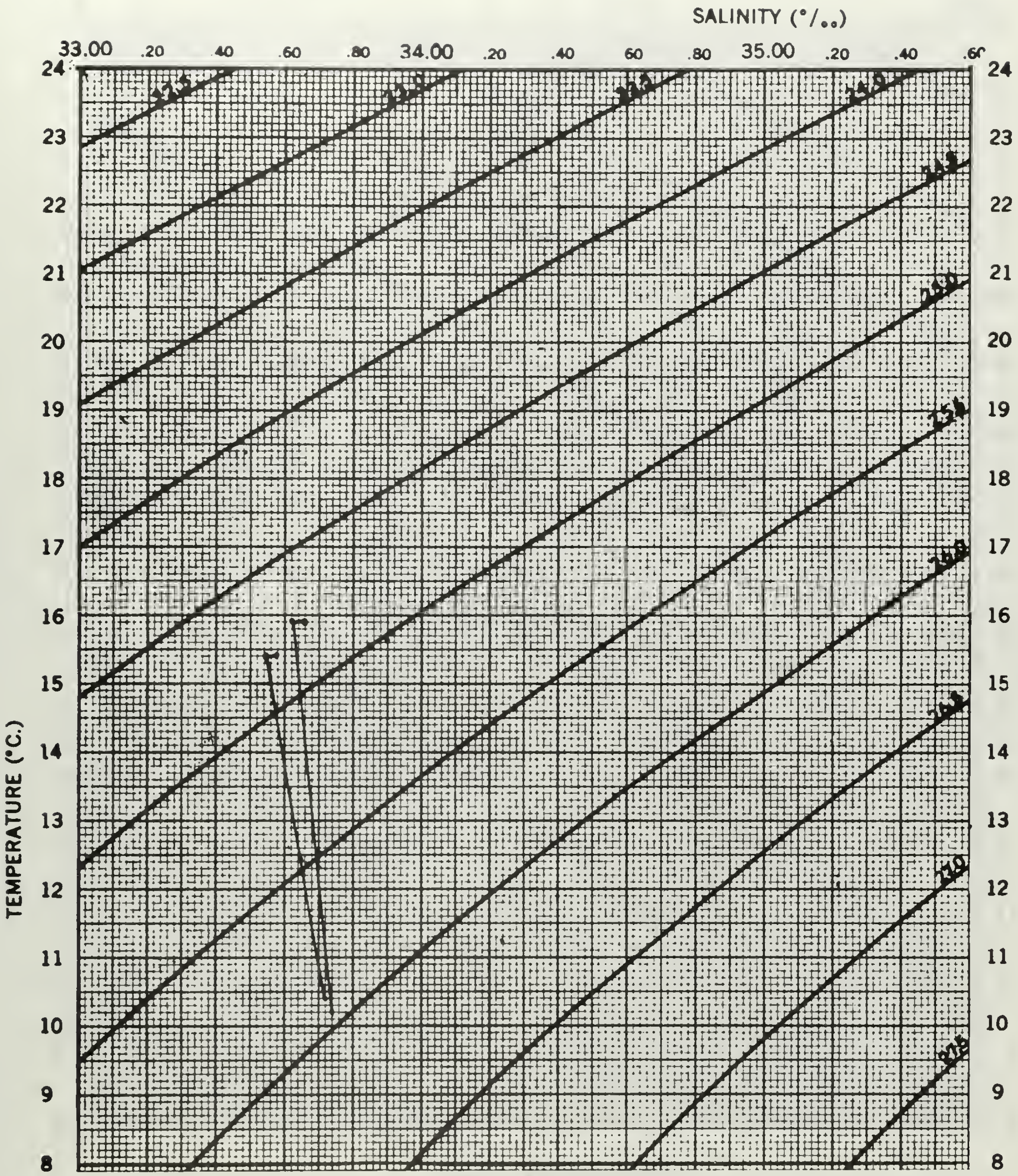
Figure 27b.



April 1959

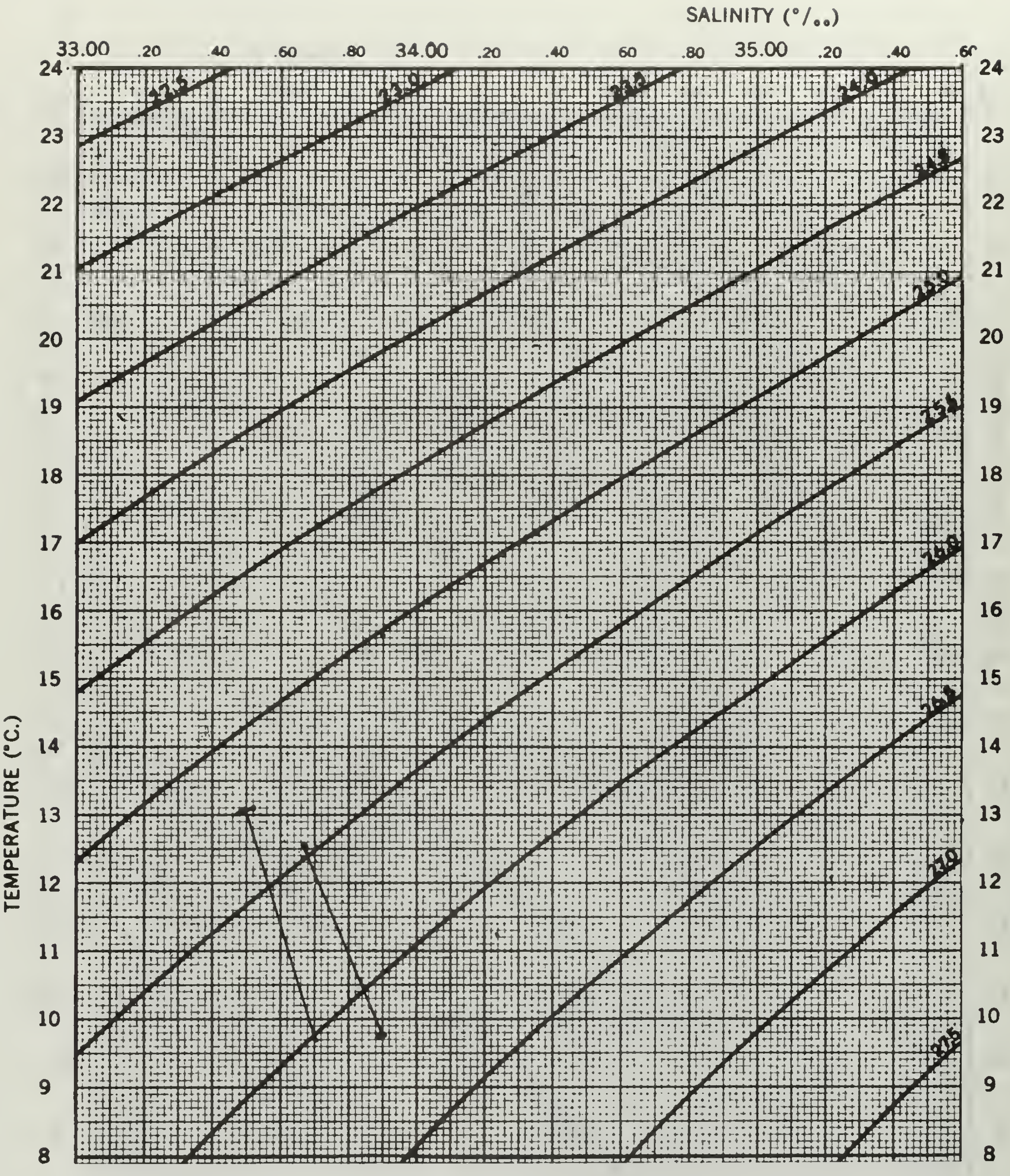
100-meter level isotherms

Figure 27e.



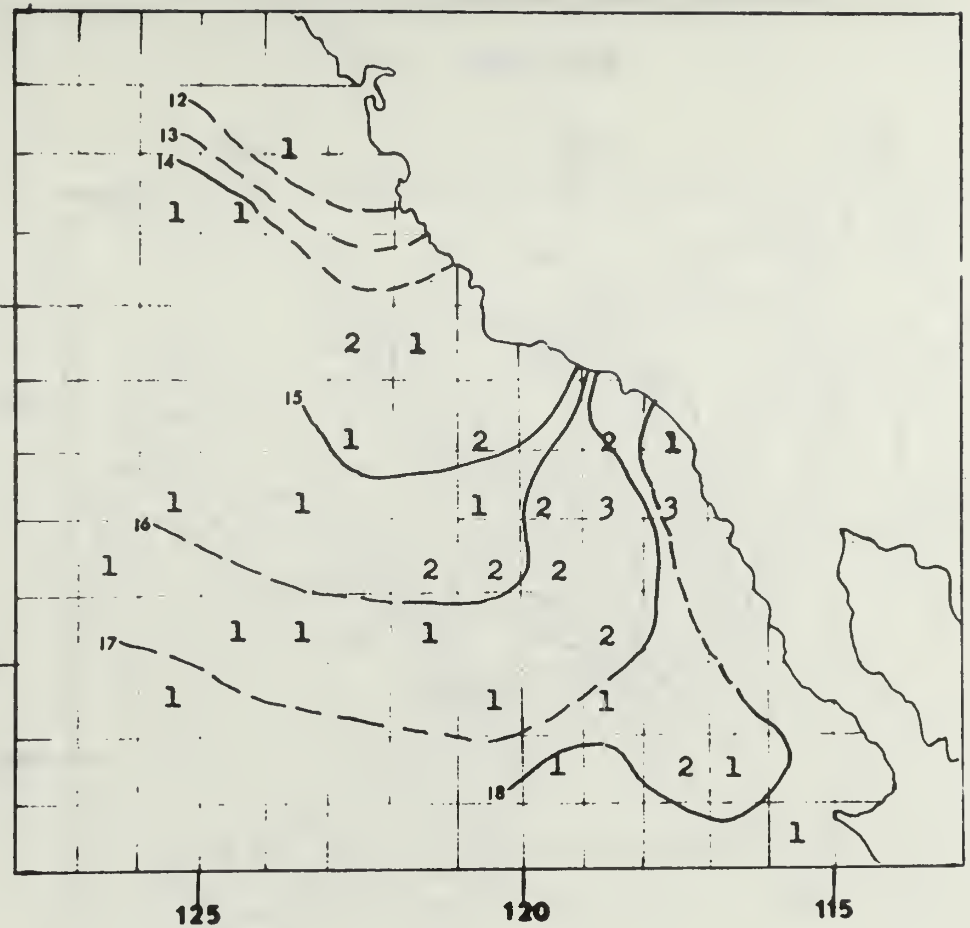
UPWELLING AREA
April 1959
29 N- 115 W

Figure 28a.



UPWELLING AREA
April 1959
34 N-120 W

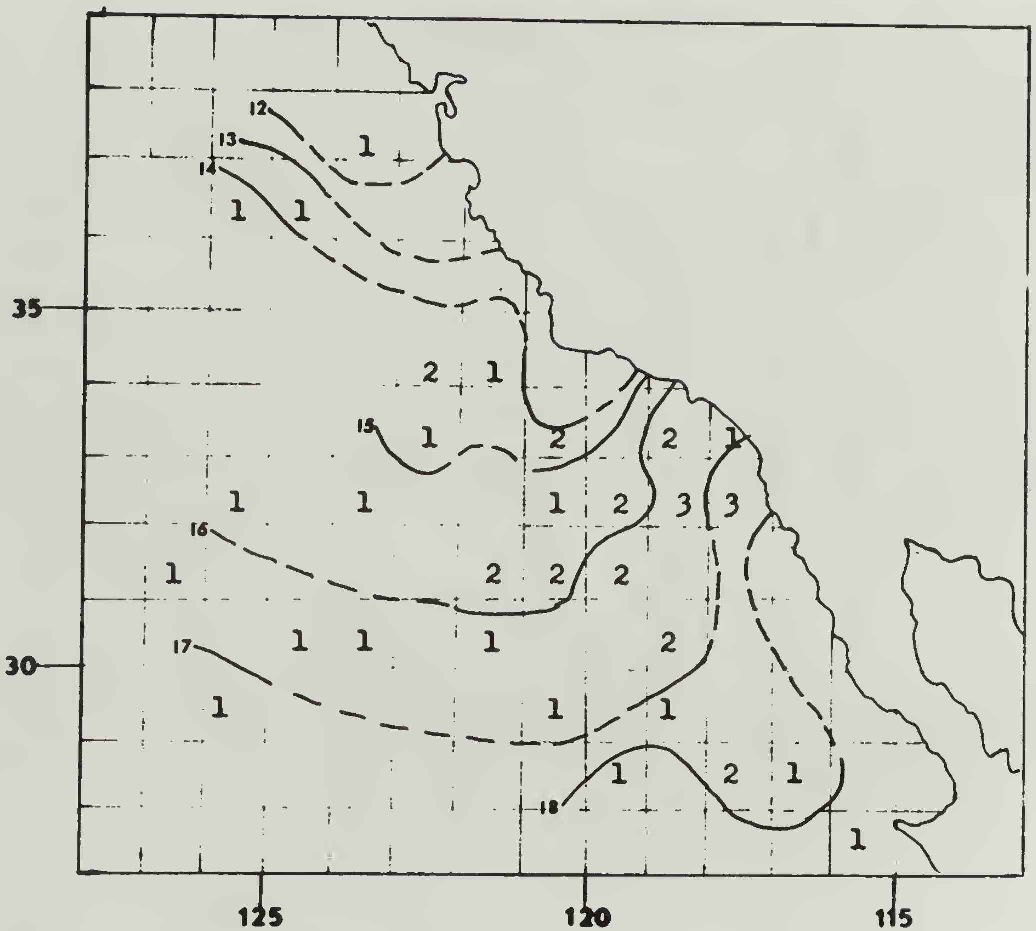
Figure 28b.



May 1959

Surface isotherms

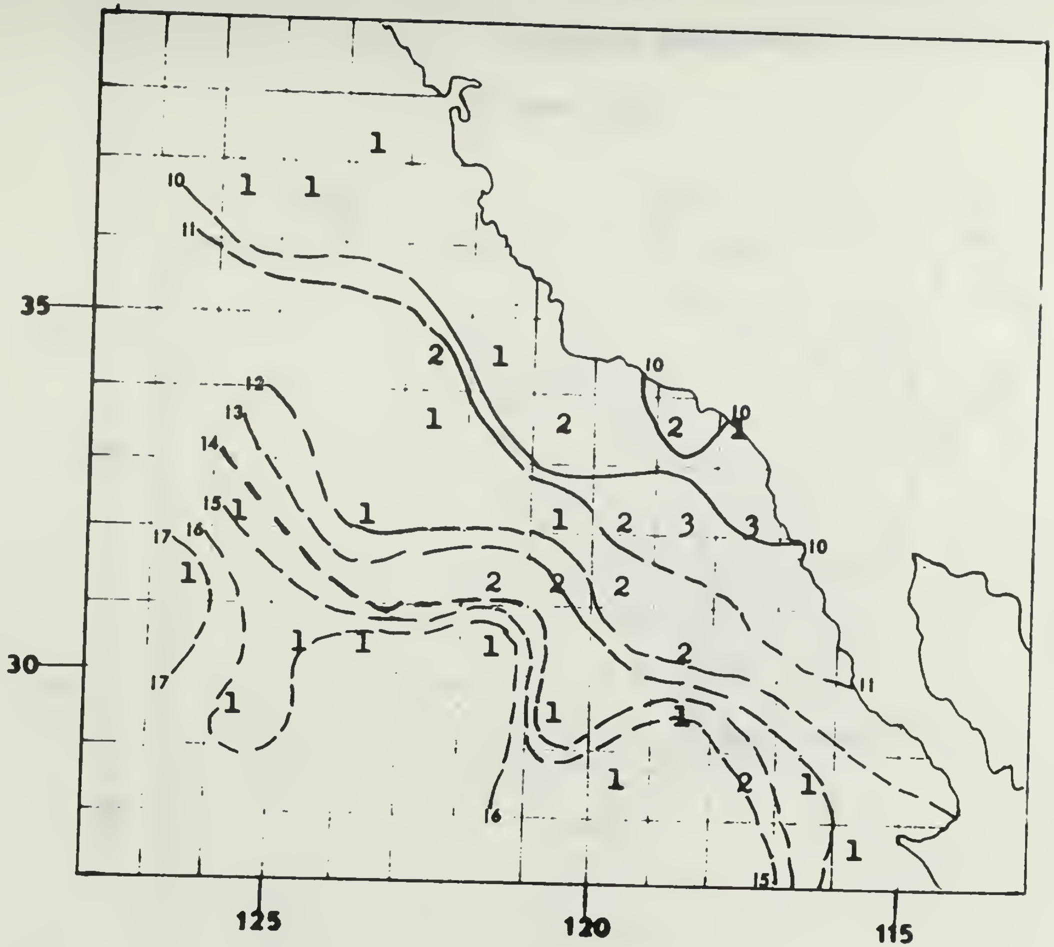
Figure 29a.



May 1959

10-meter level isotherms

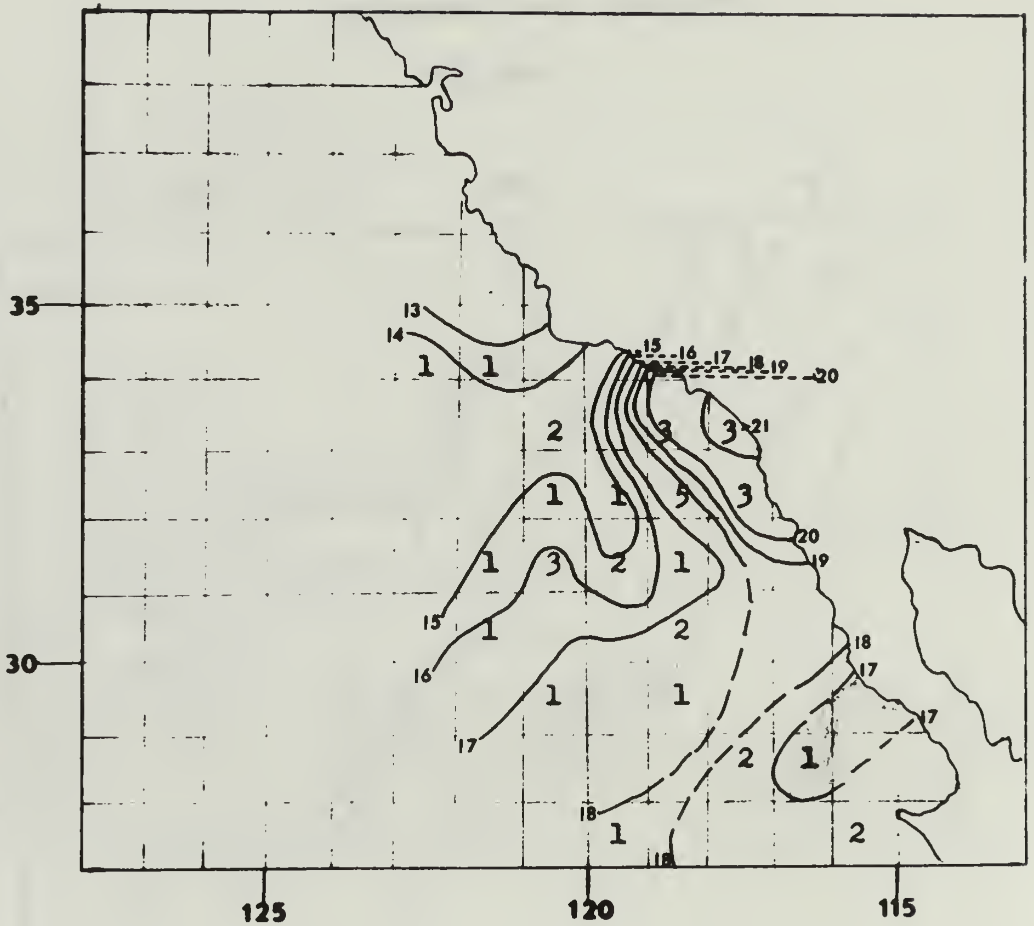
Figure 29b.



May 1959

100-meter level isotherms

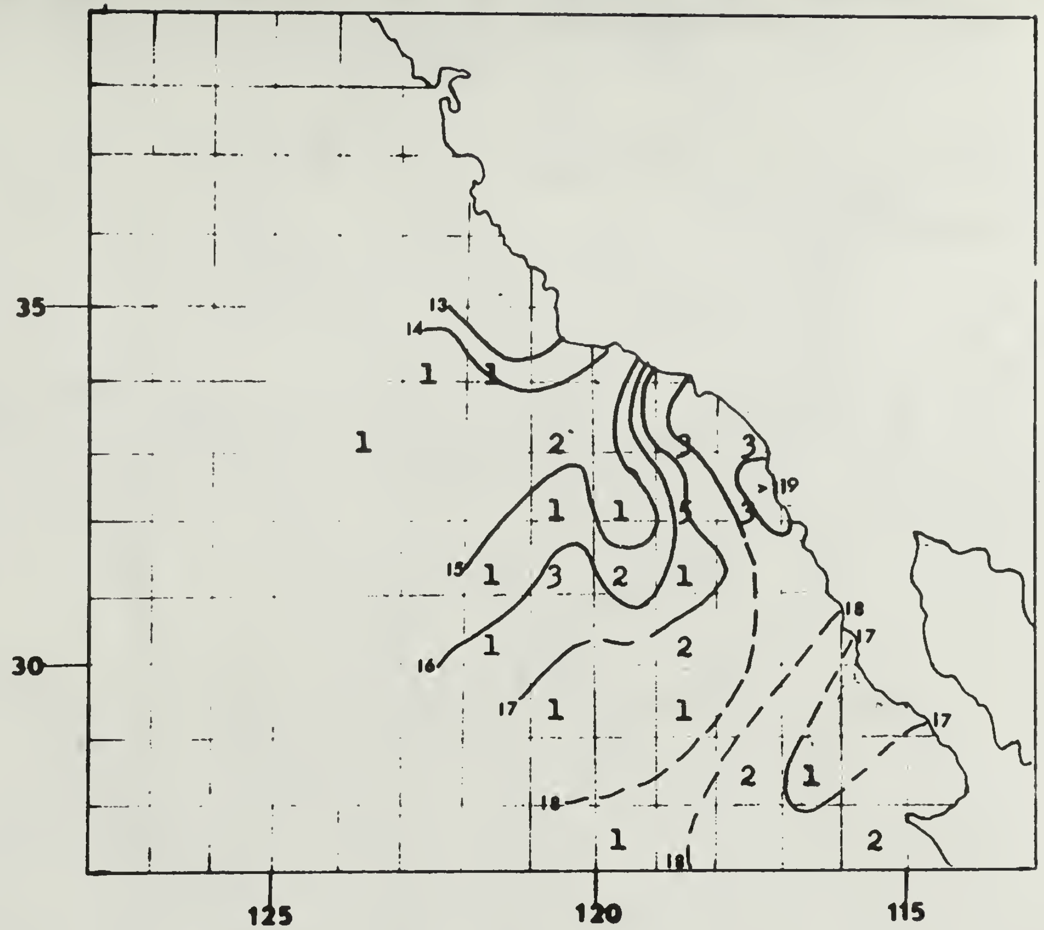
Figure 29e.



June 1959

Surface isotherms

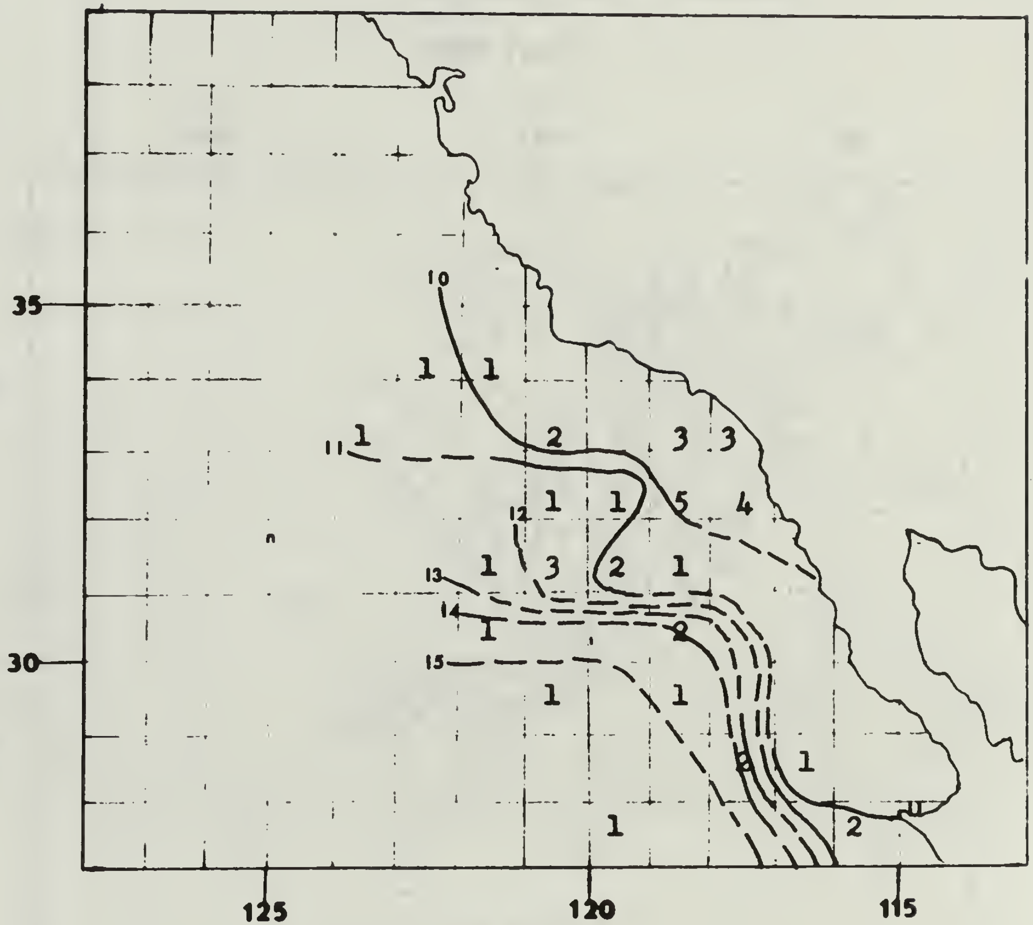
Figure 30a.



June 1959

10-meter level isotherms

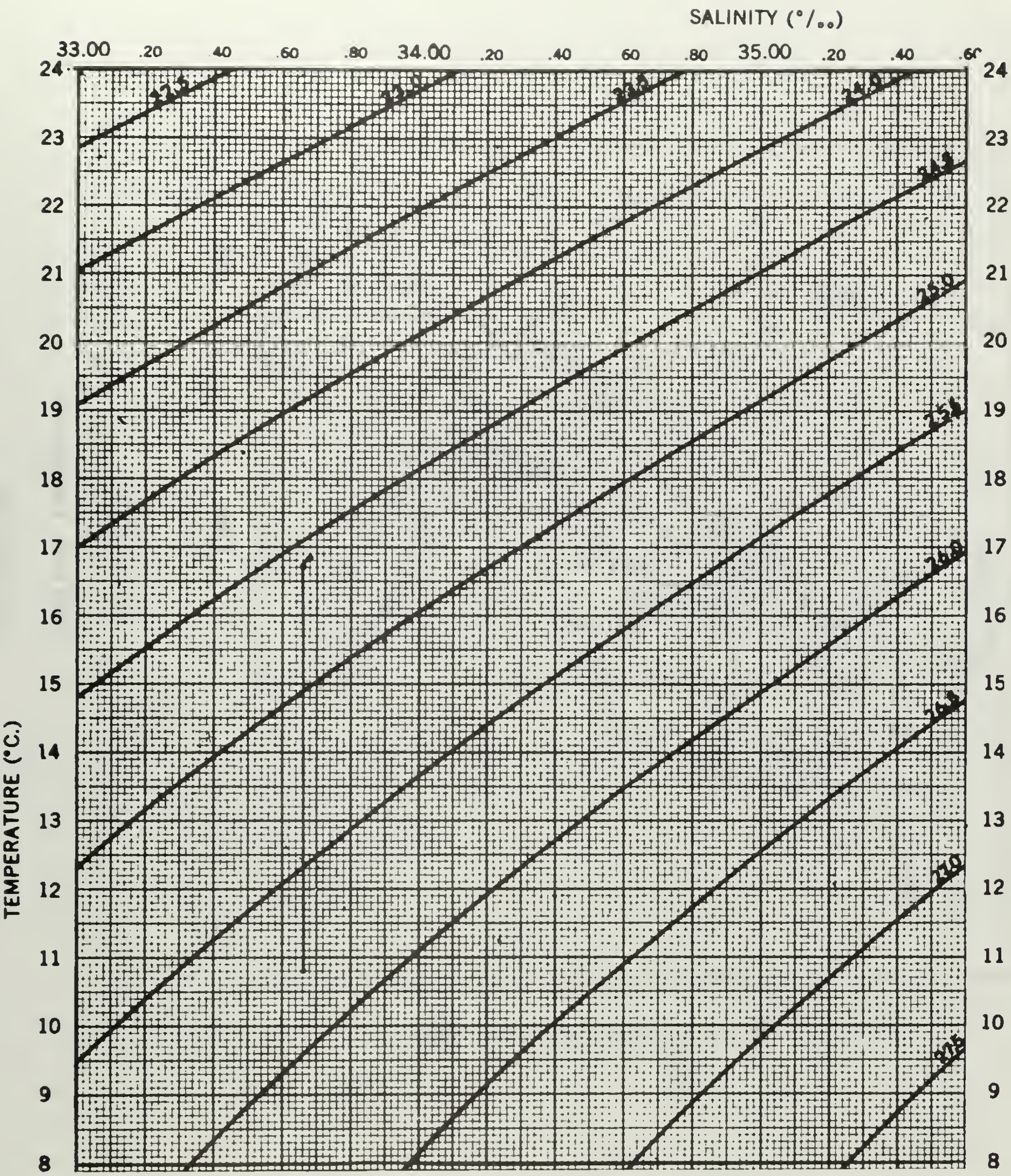
Figure 30b.



June 1959

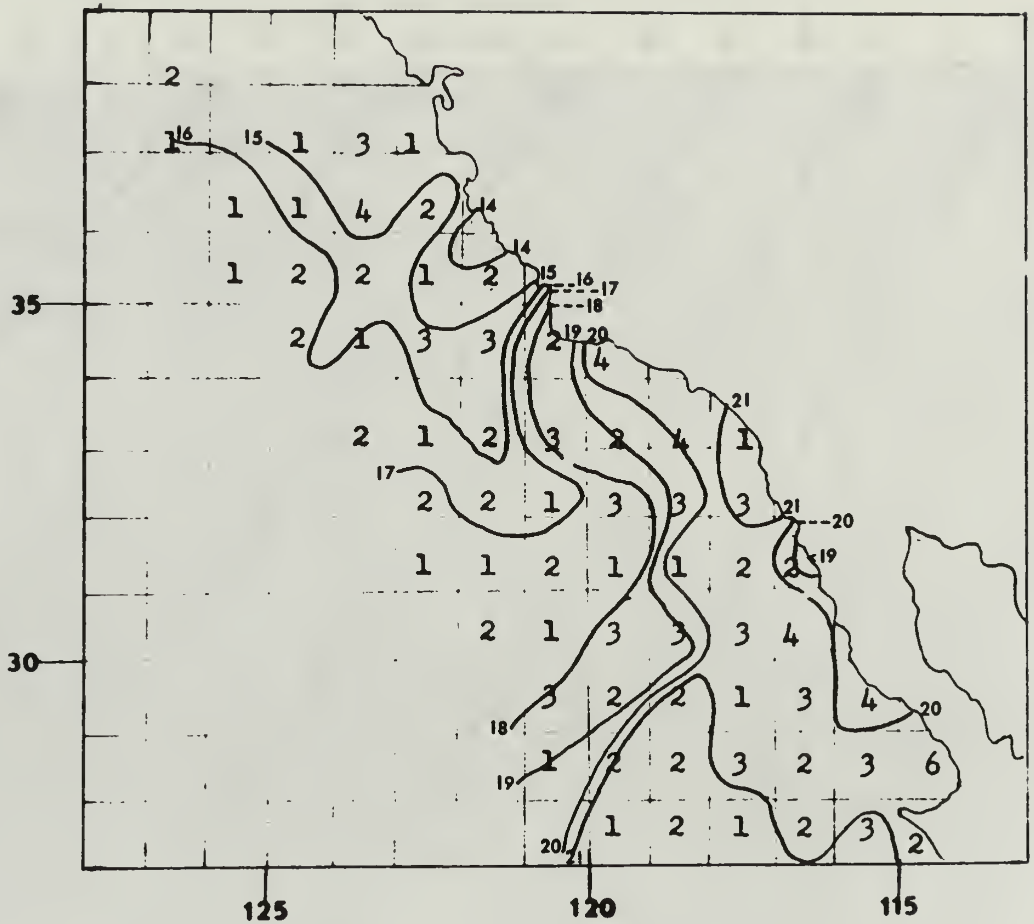
100-meter level isotherms

Figure 30c.



UPWELLING AREA
June 1959
28 N-116 W

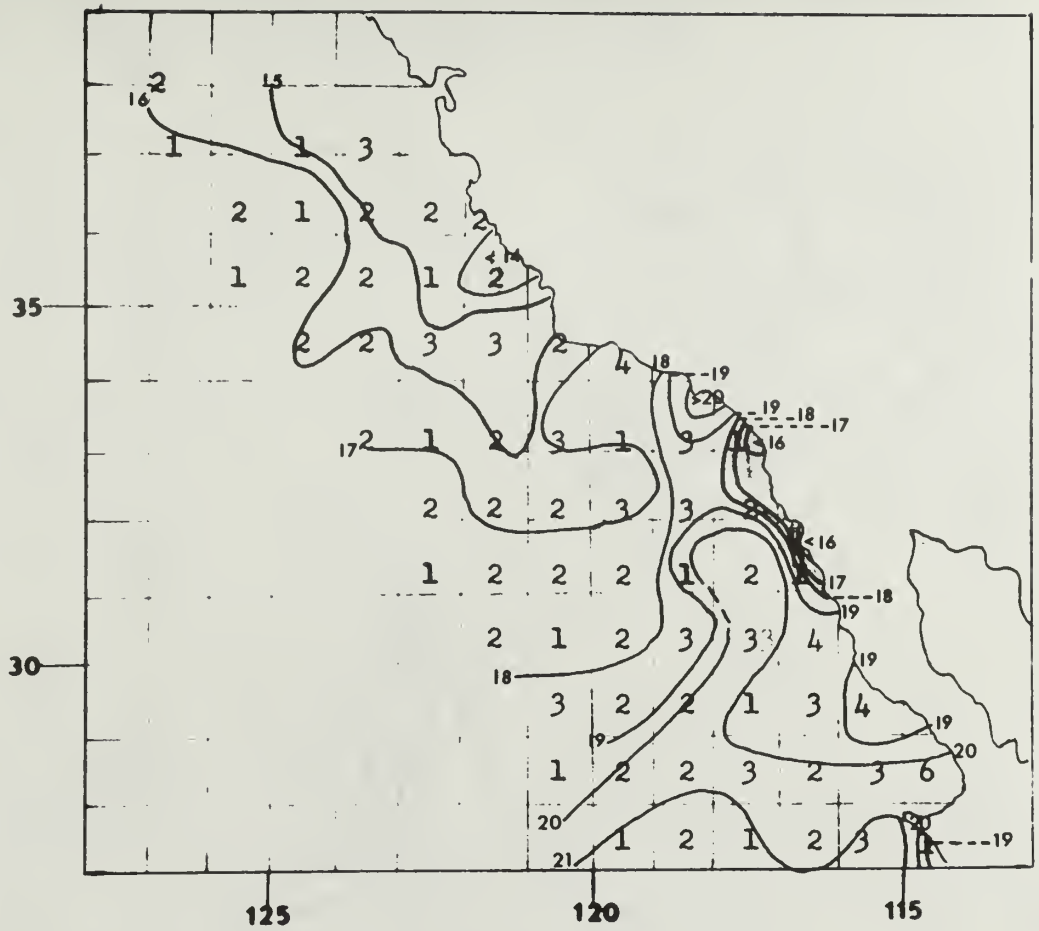
Figure 31a.



July 1959

Surface isotherms

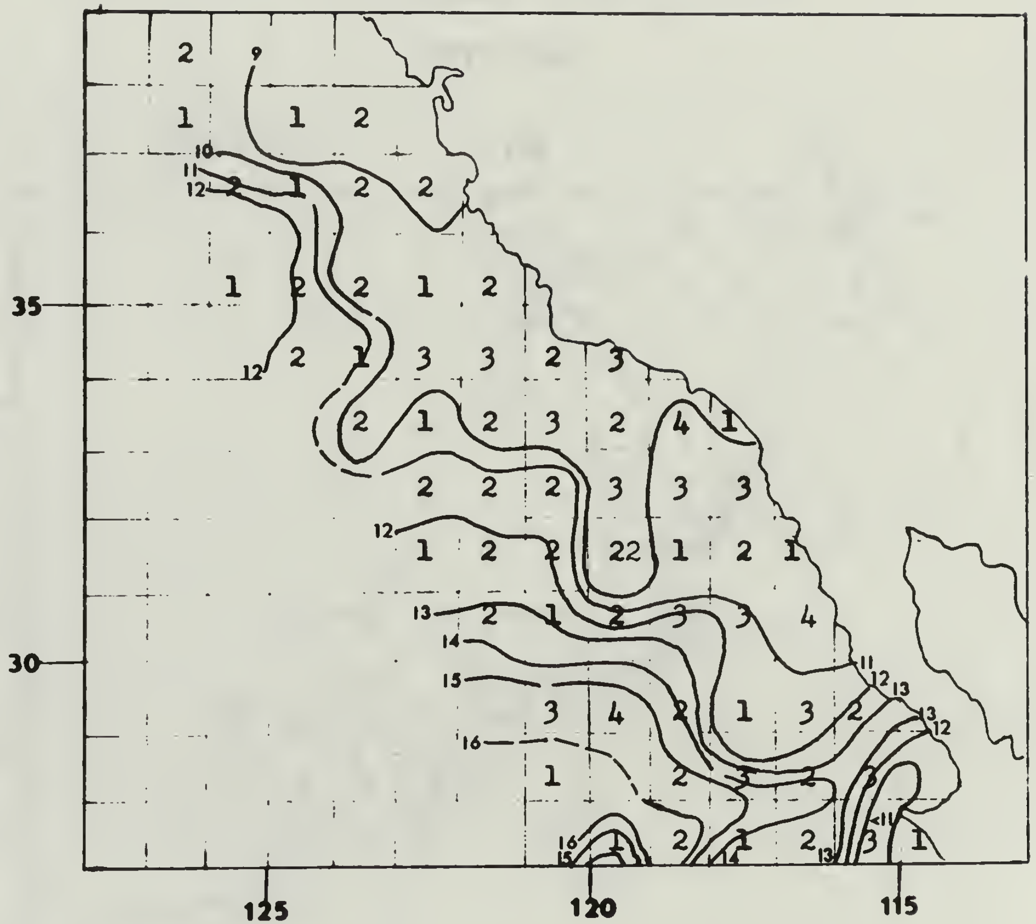
Figure 32a.



July 1959

10-meter level isotherms

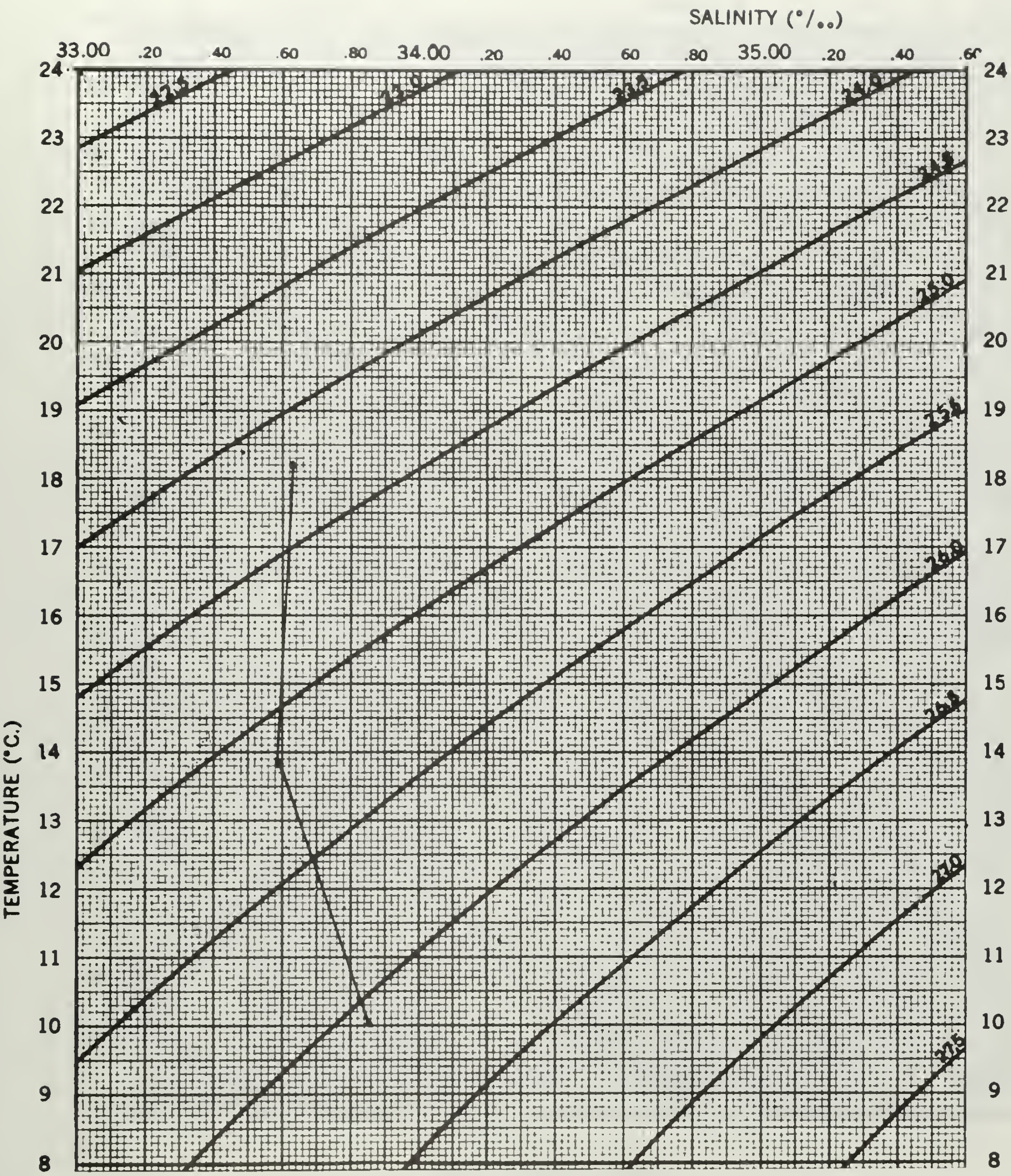
Figure 32b.



July 1959

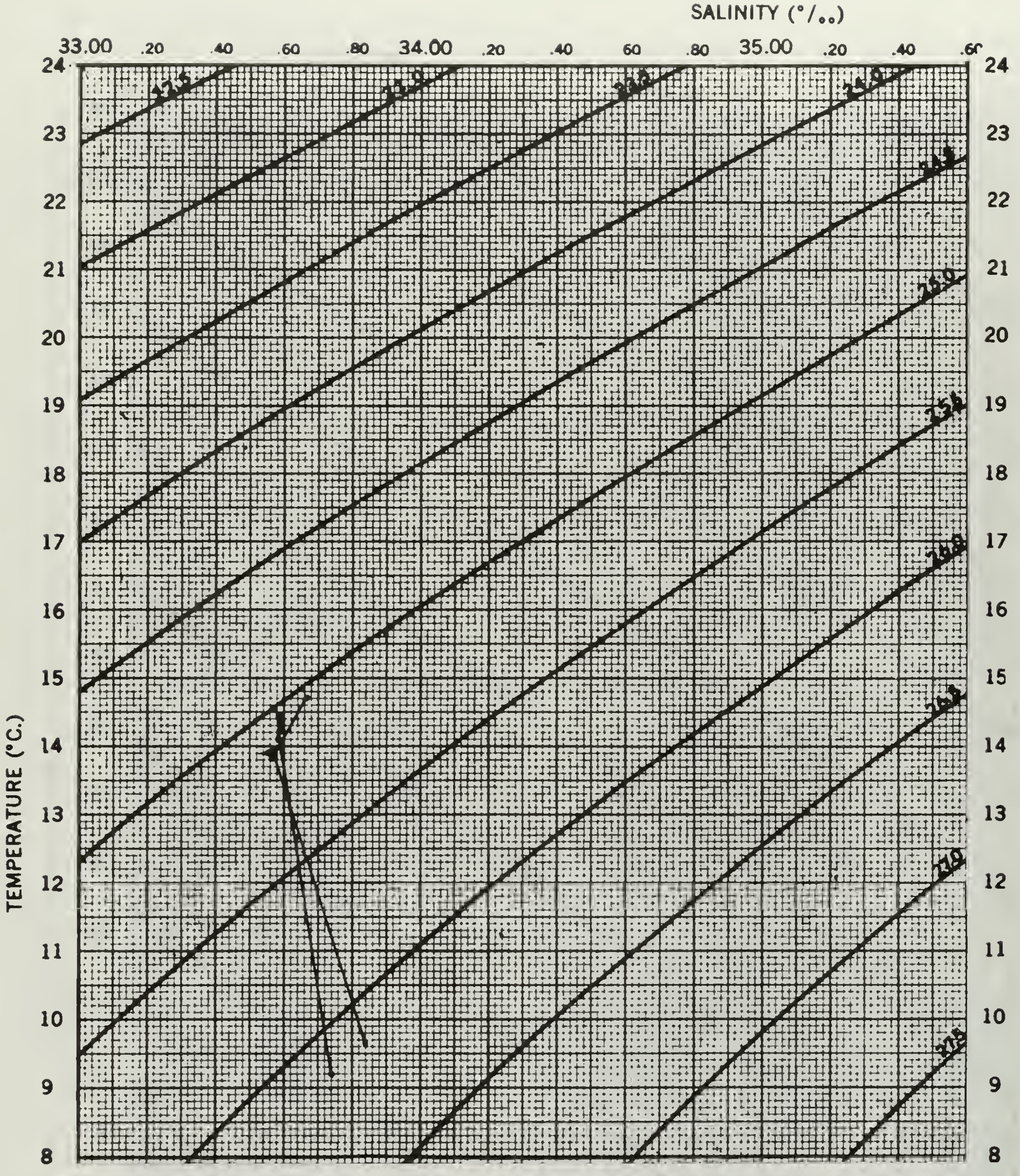
100-meter level isotherms

Figure 32c.



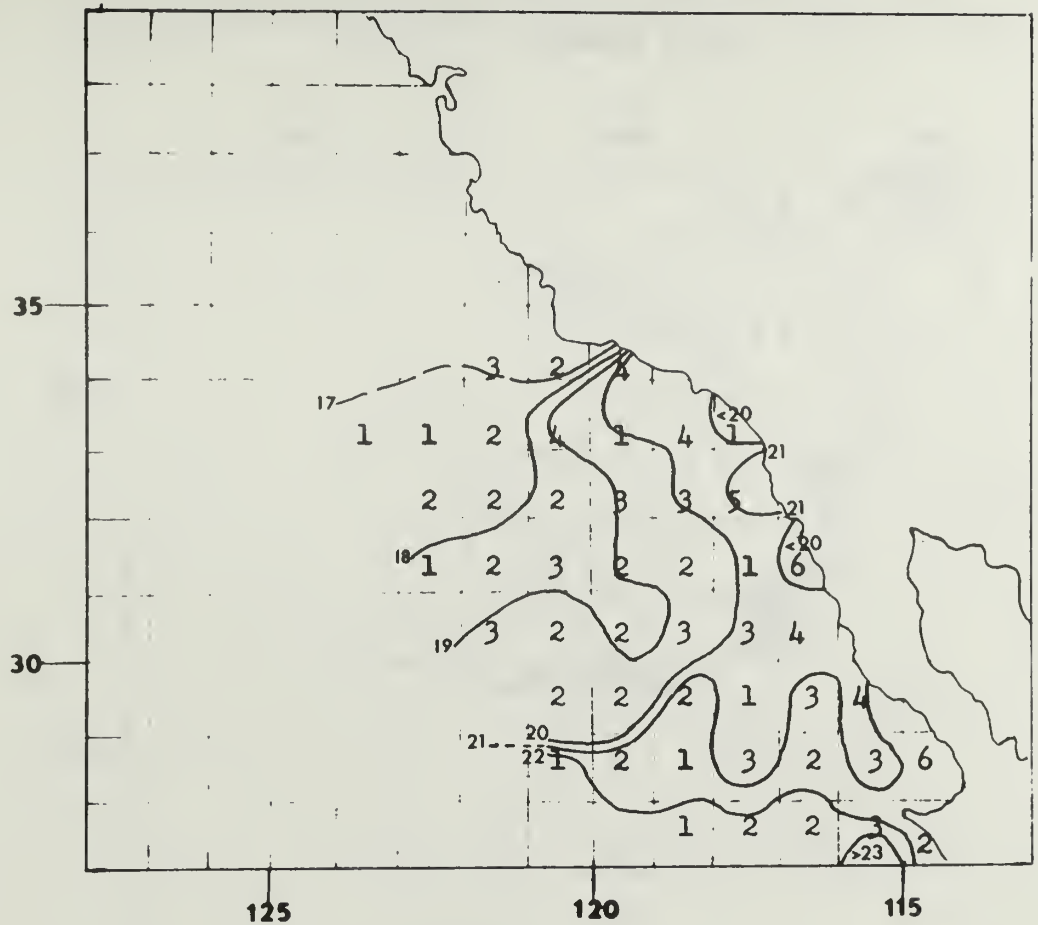
UPWELLING AREA
July 1959
31 N-116 W

Figure 33a.



UPWELLING AREA
July 1959
35 N-121 W

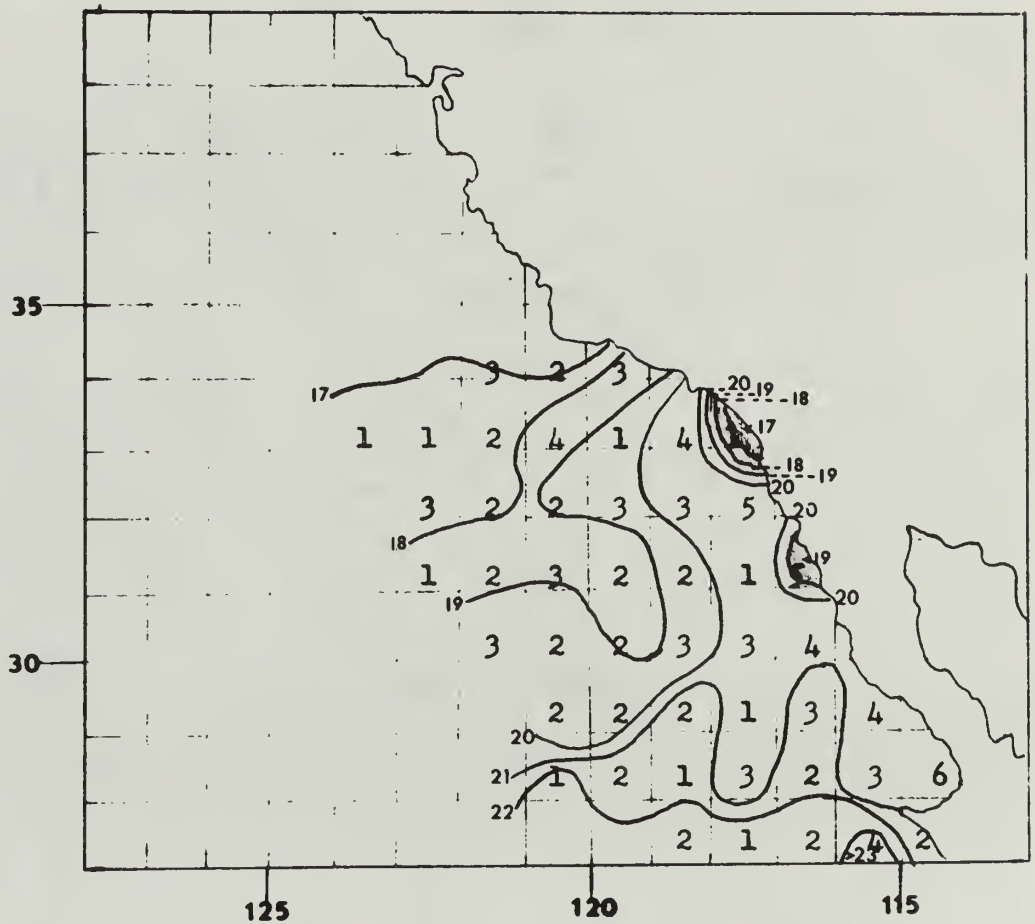
Figure 33b.



August 1959

Surface isotherms

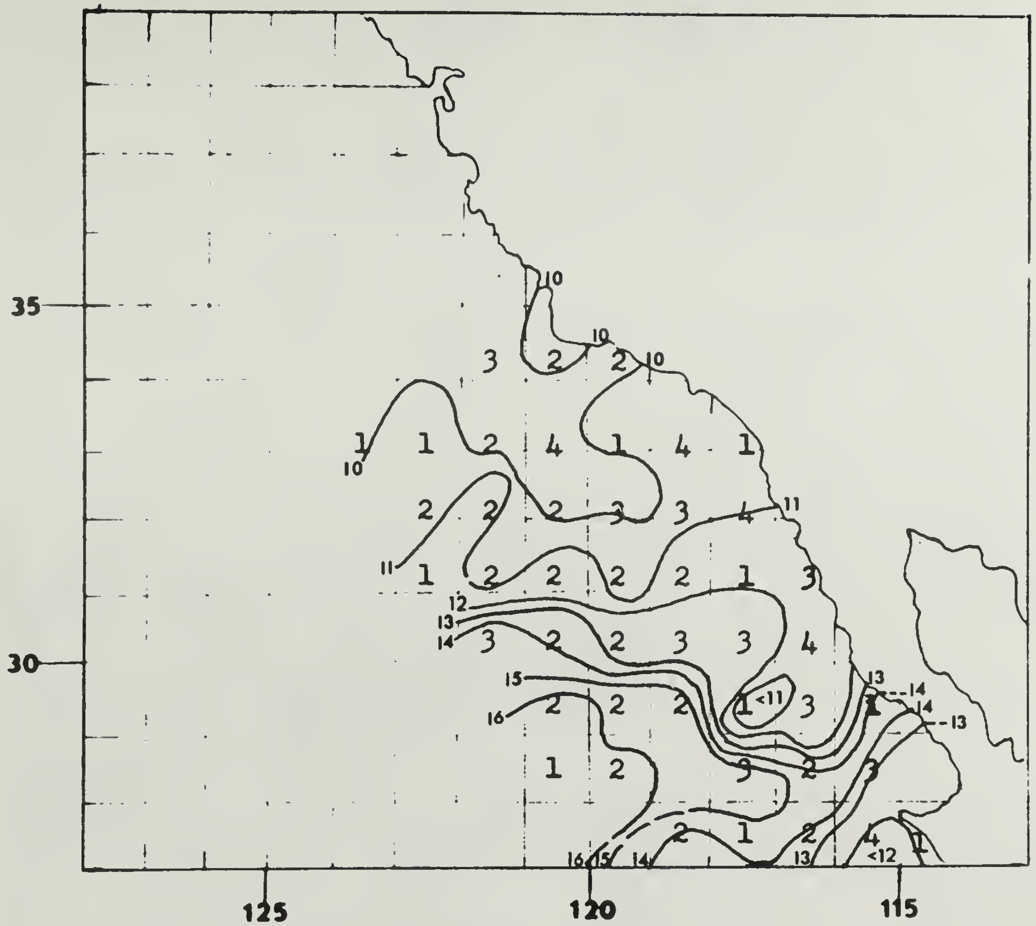
Figure 34a.



August 1959

10-meter level isotherms

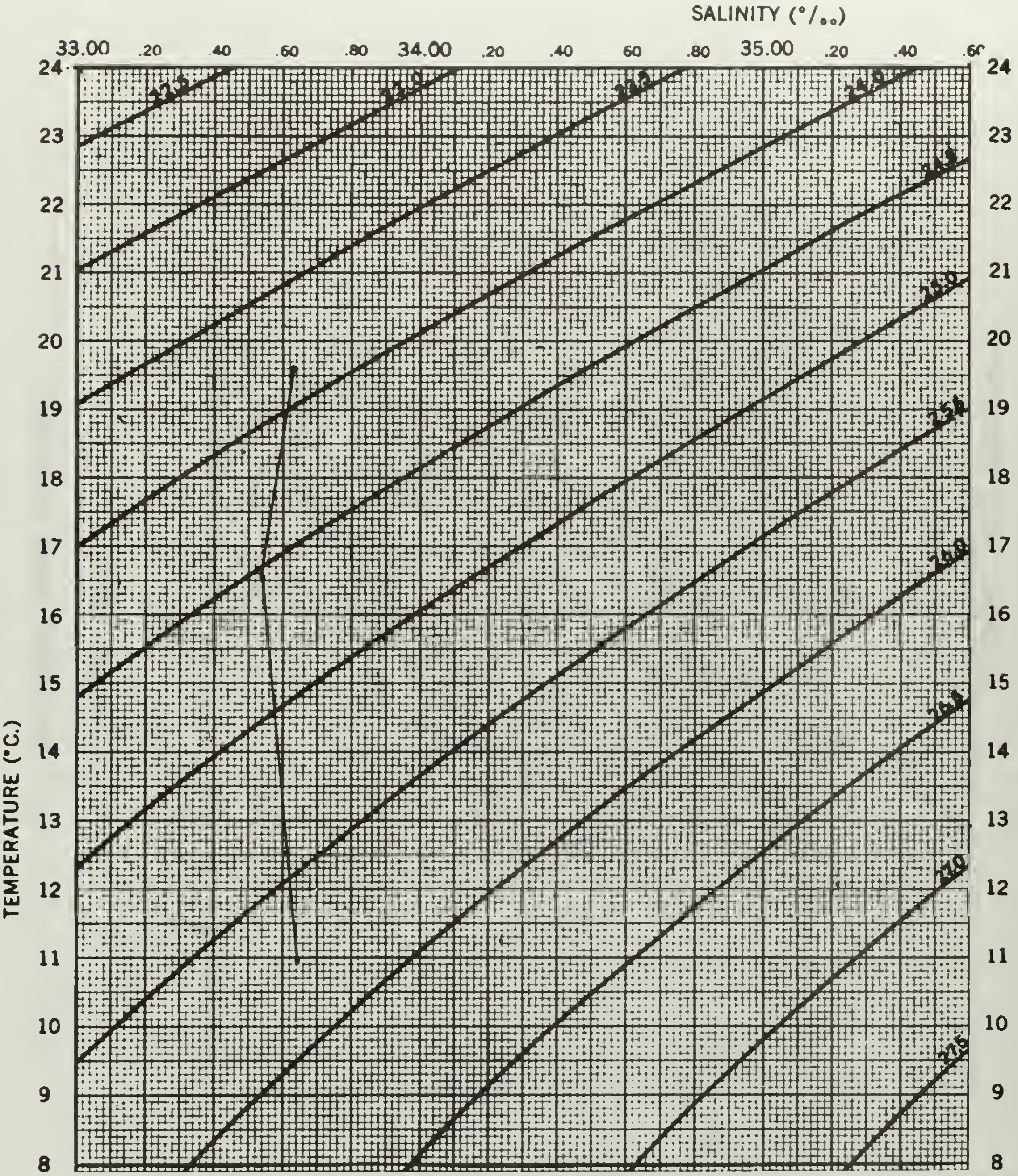
Figure 34b.



August 1959

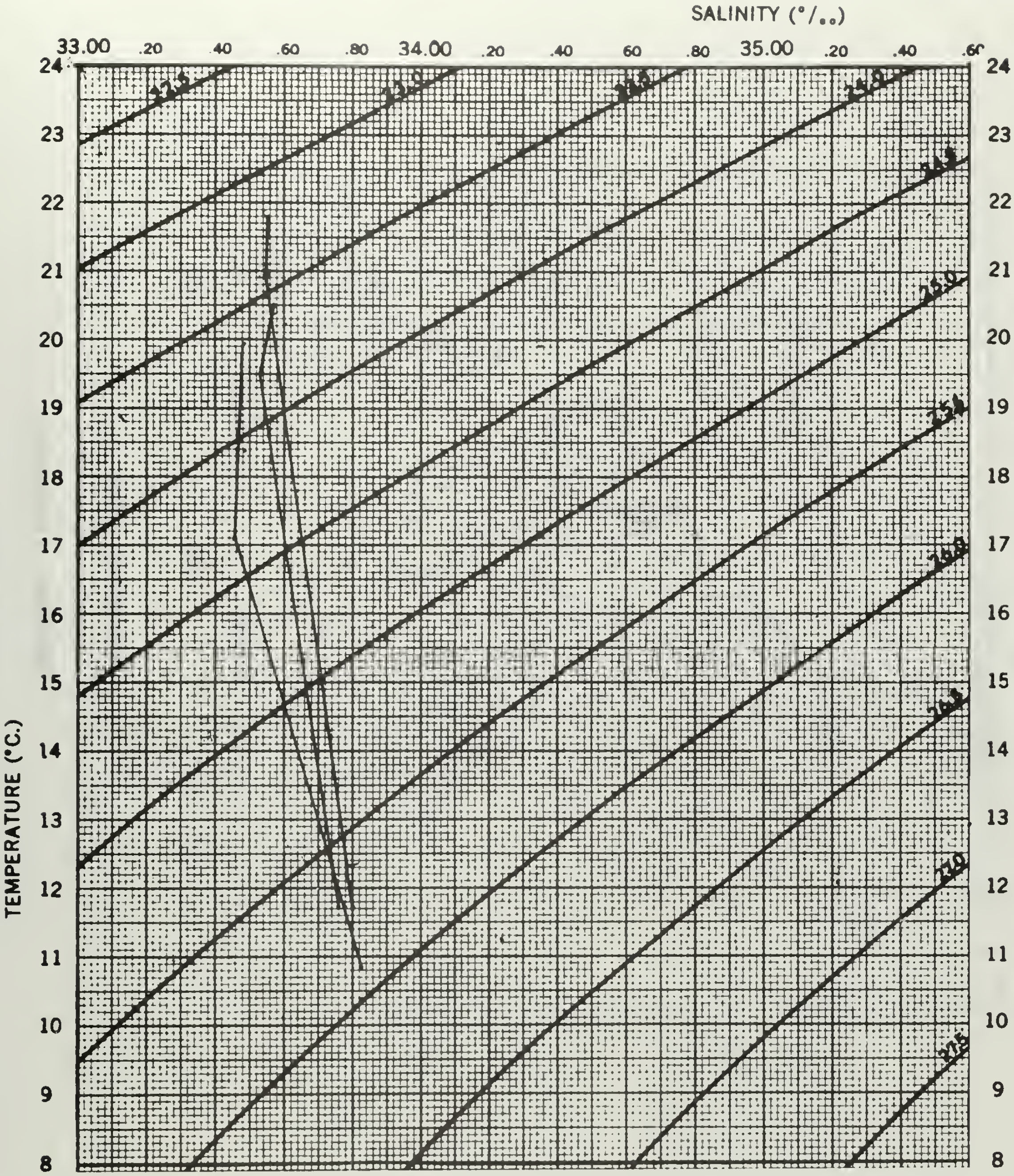
100-meter level isotherms

Figure 34c.



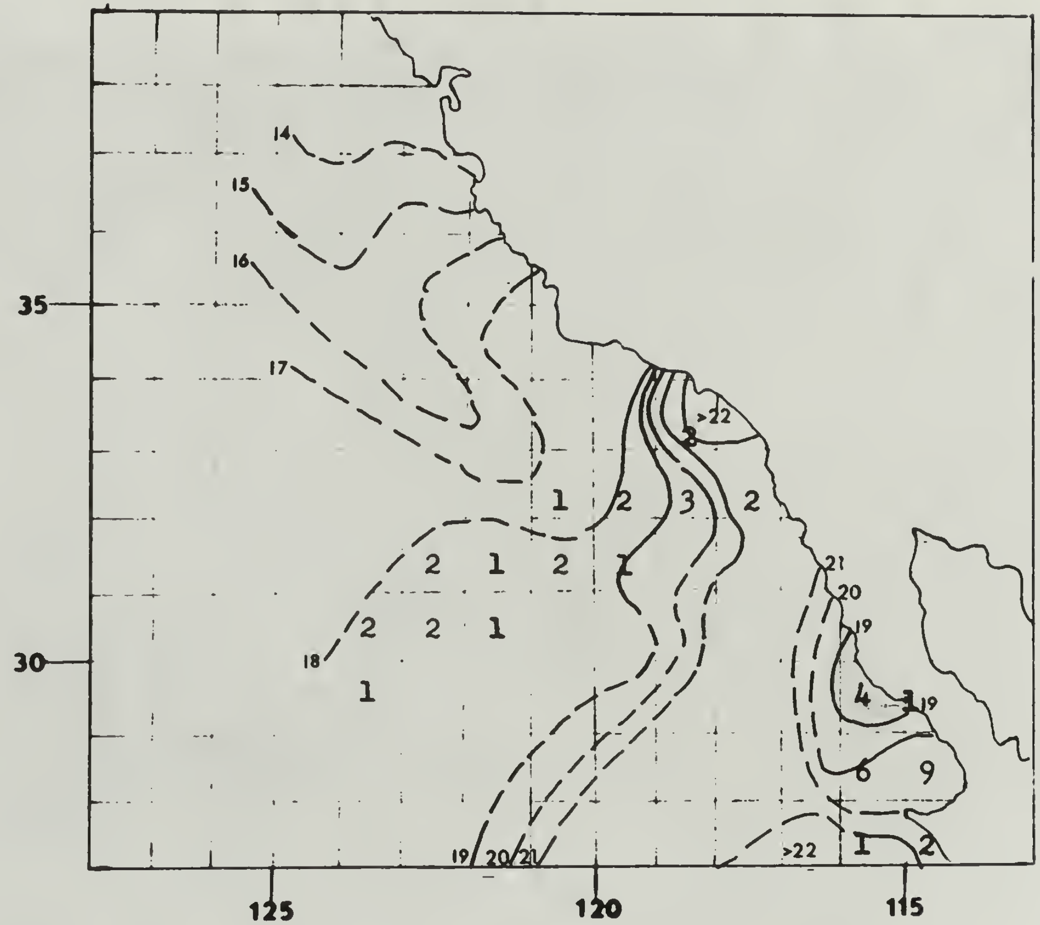
UPWELLING AREA
August 1959
33 N-117 W

Figure 35a.



UPWELLING AREA
August 1959
31 N-116 W

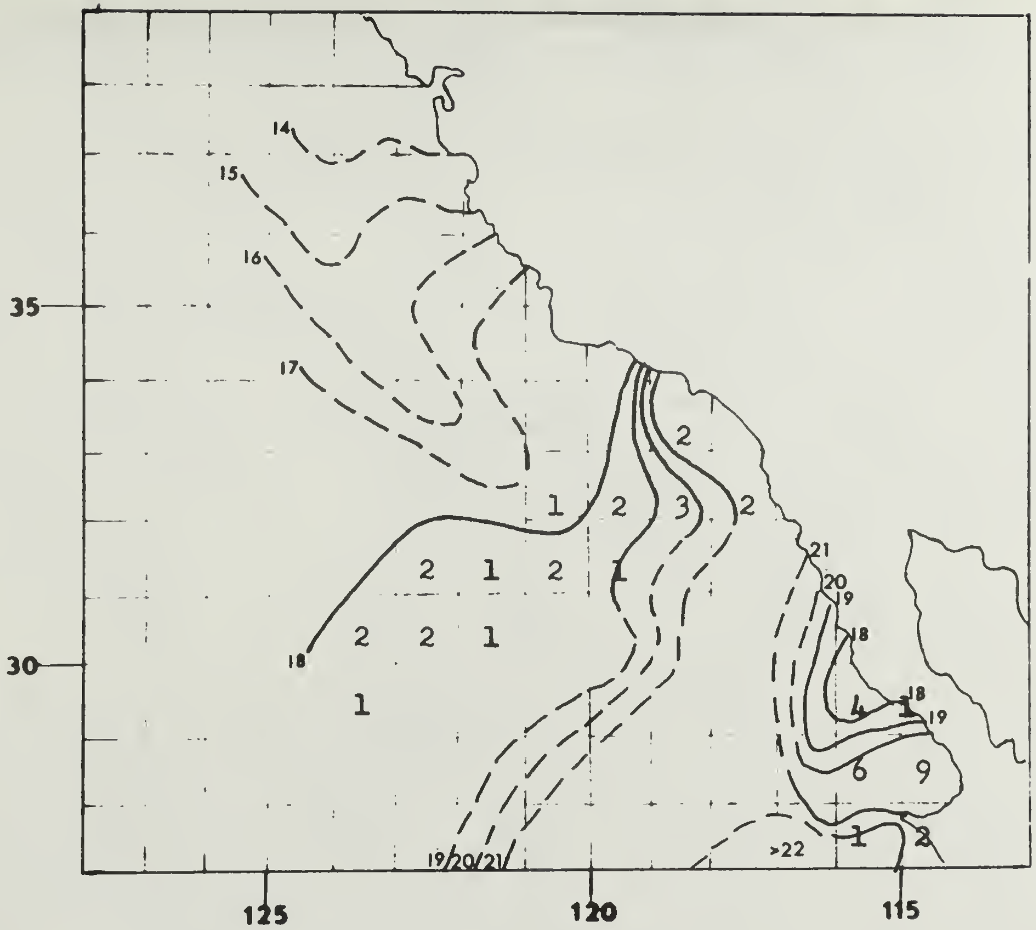
Figure 35b



September 1959

Surface isotherms

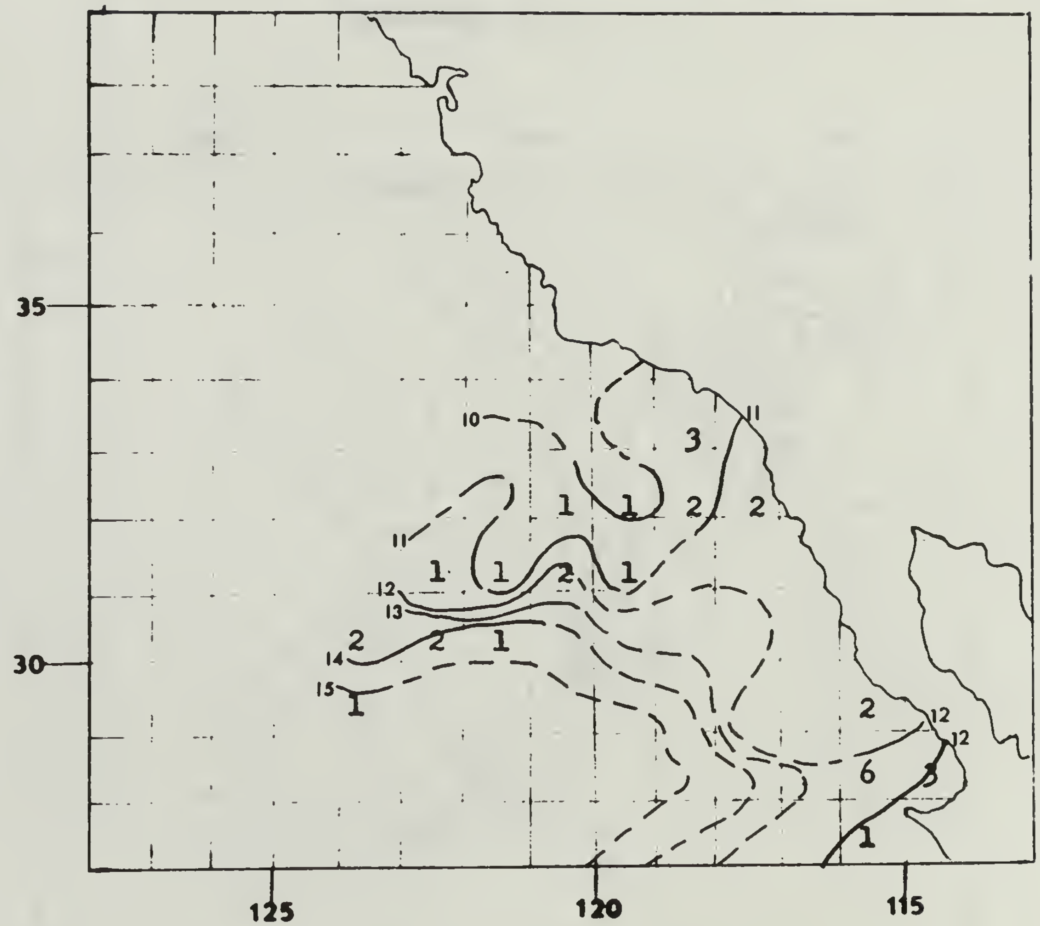
Figure 36a.



September 1959

10-meter level isotherms

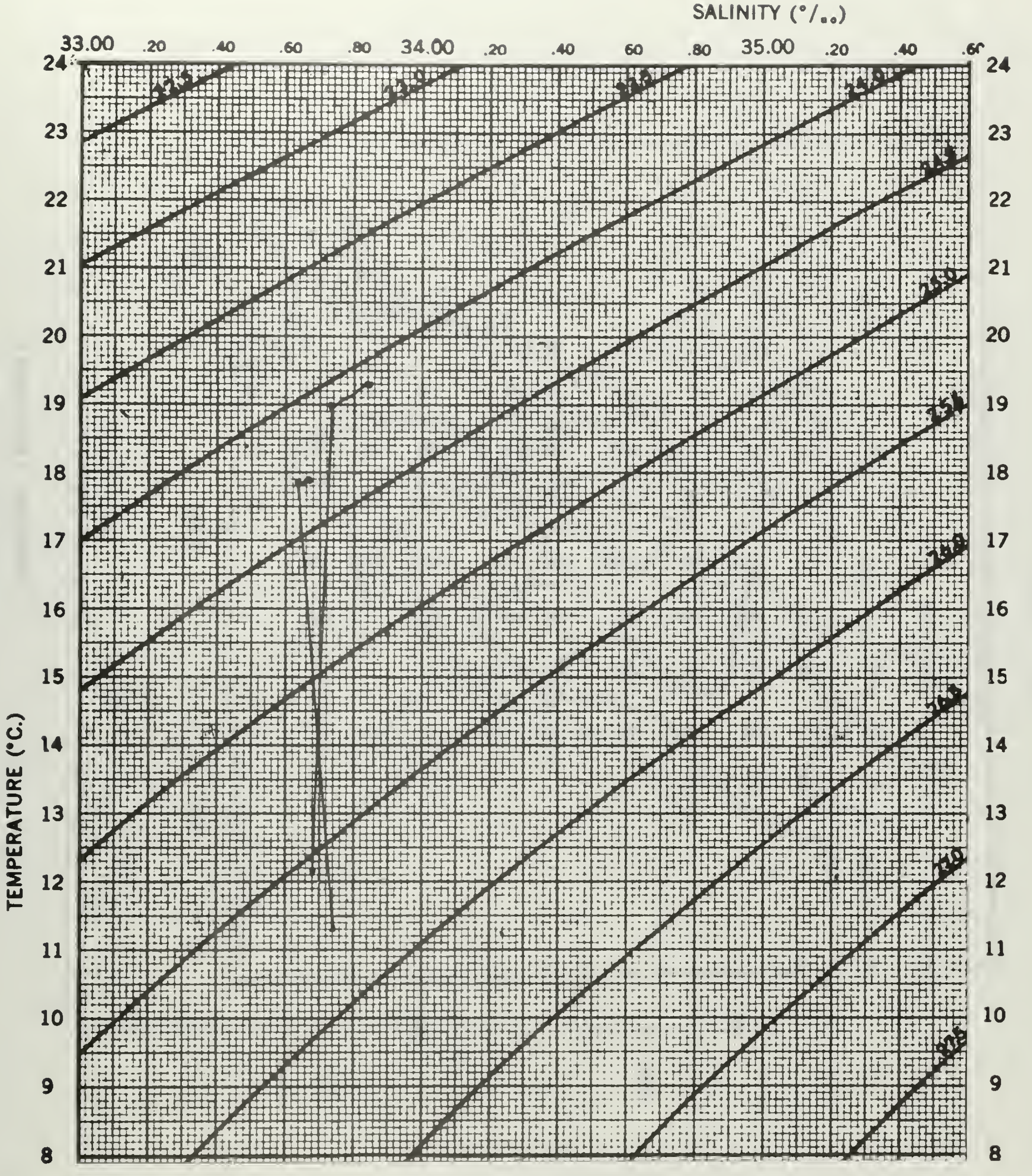
Figure 36b.



September 1959

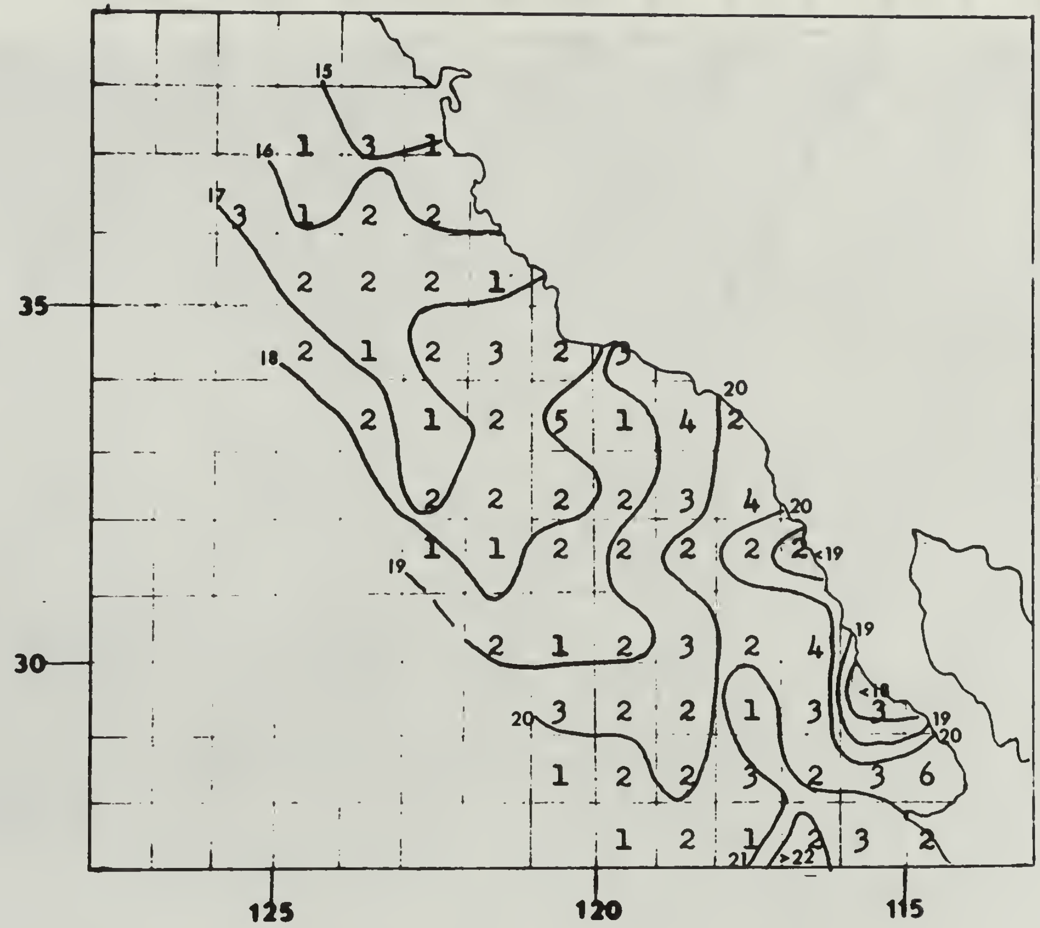
100-meter level isotherms

Figure 36c.



UPWELLING AREA
September 1959
29 N-115 W

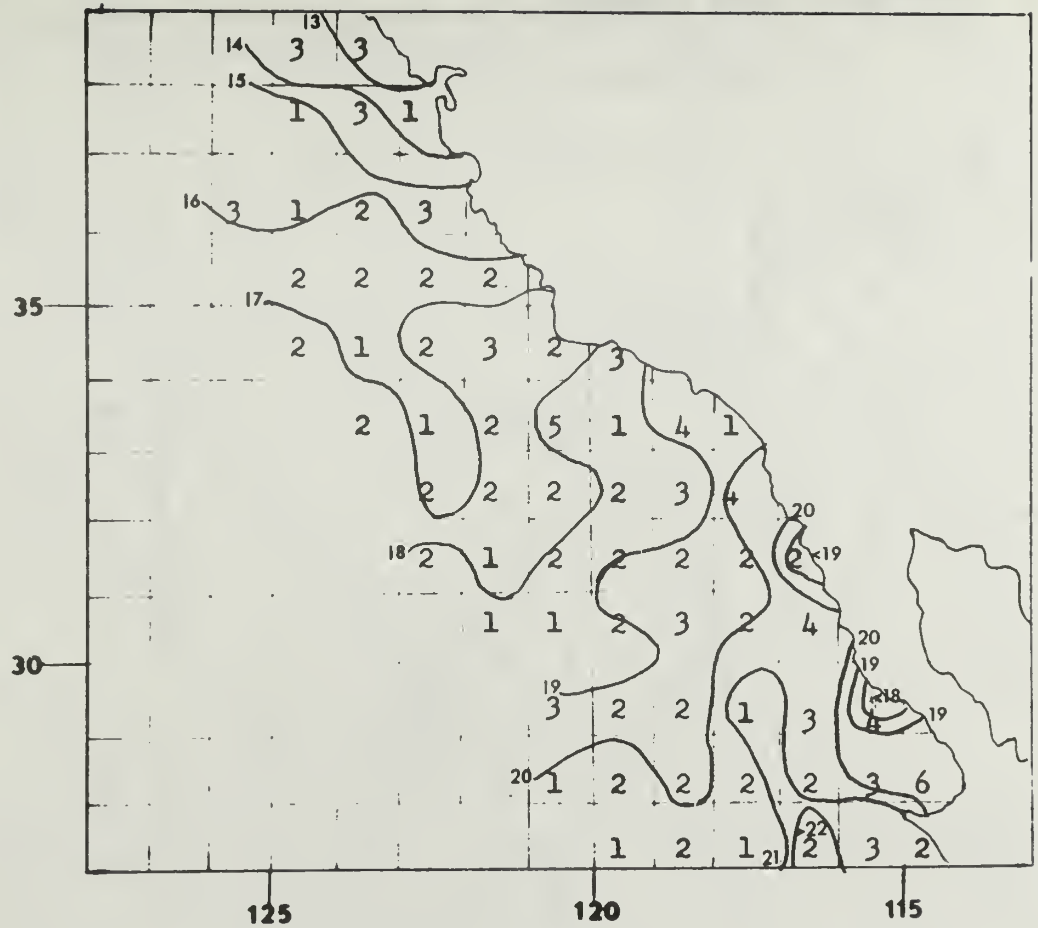
Figure 37a.



October 1959

Surface isotherms

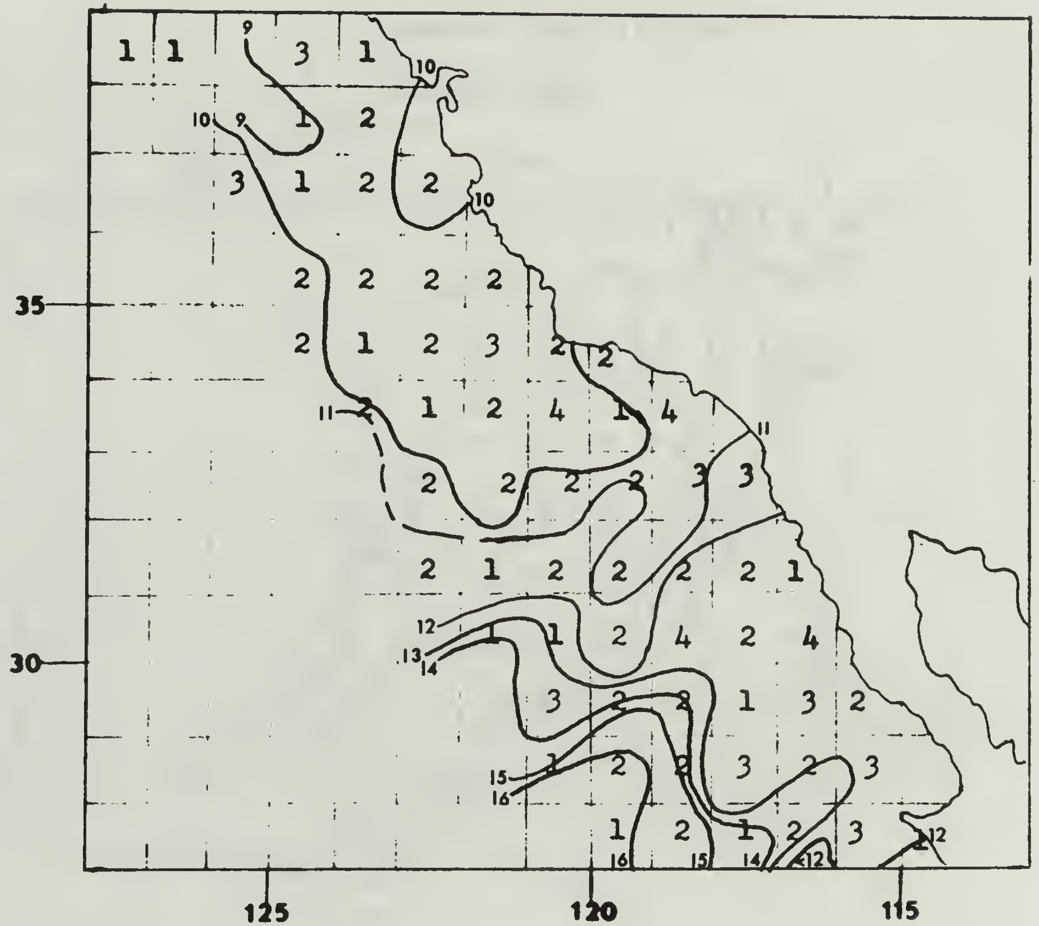
Figure 38a.



October 1959

10—meter level isotherms

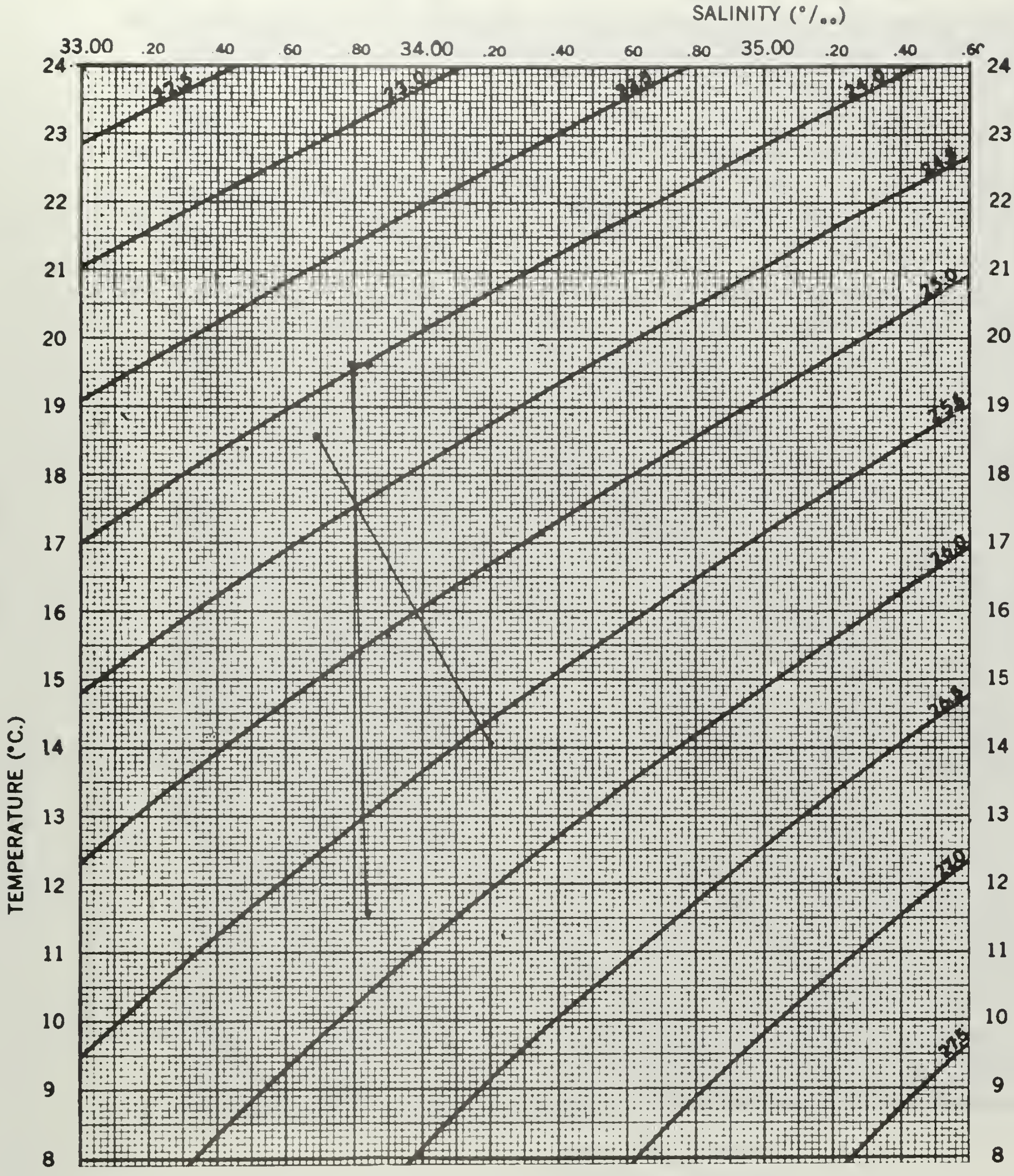
Figure 38b.



October 1959

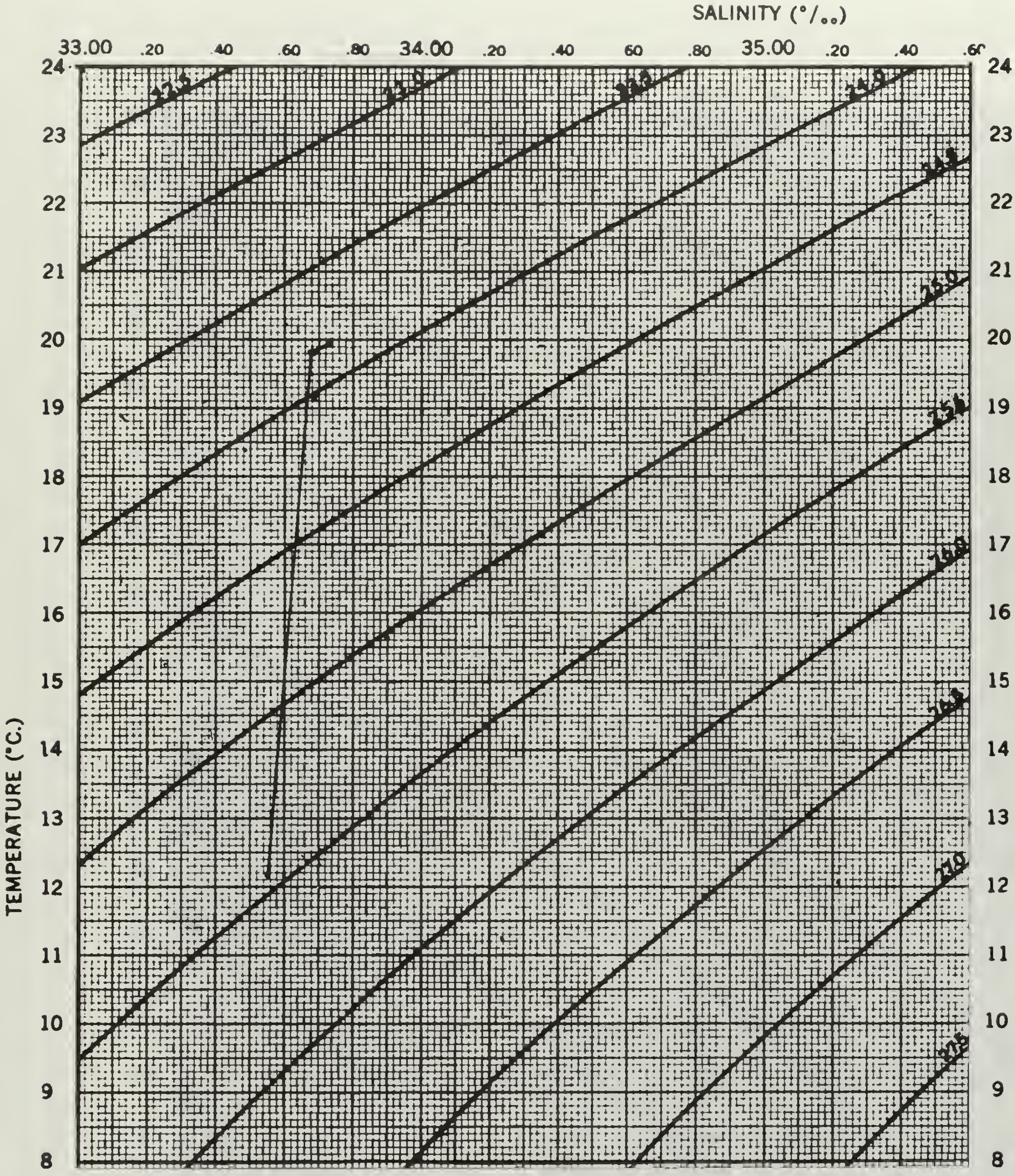
100-meter level isotherms

Figure 38c.



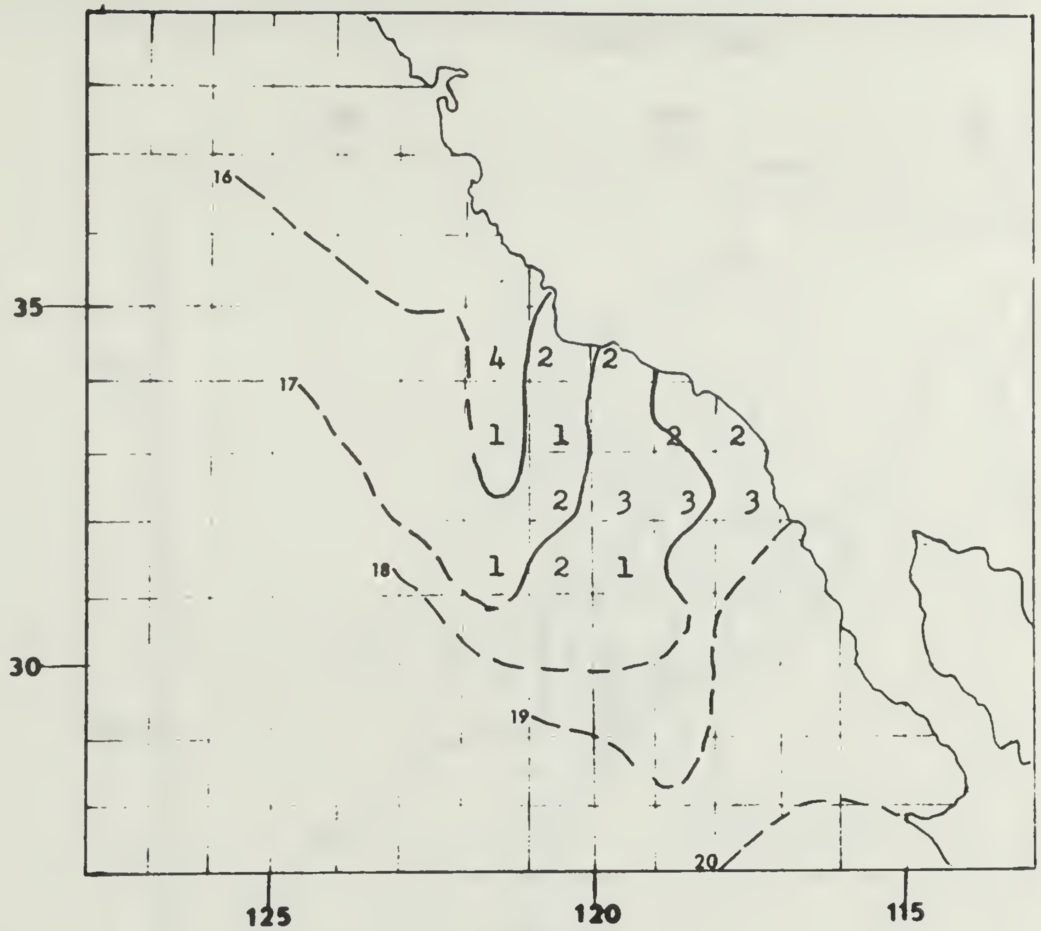
UPWELLING AREA
October 1959
29 N-115 W

Figure 39a.



UPWELLING AREA
October 1959
31 N-116 W

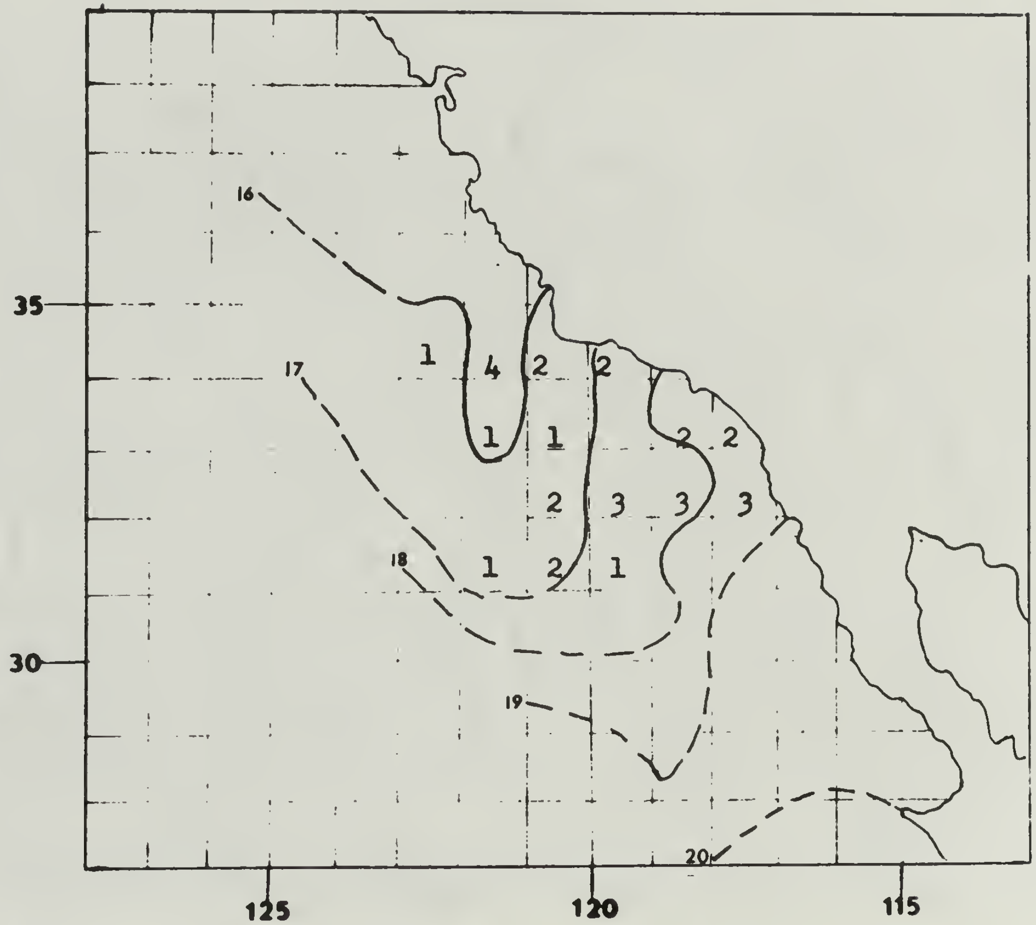
Figure 39b.



November 1959

Surface isotherms

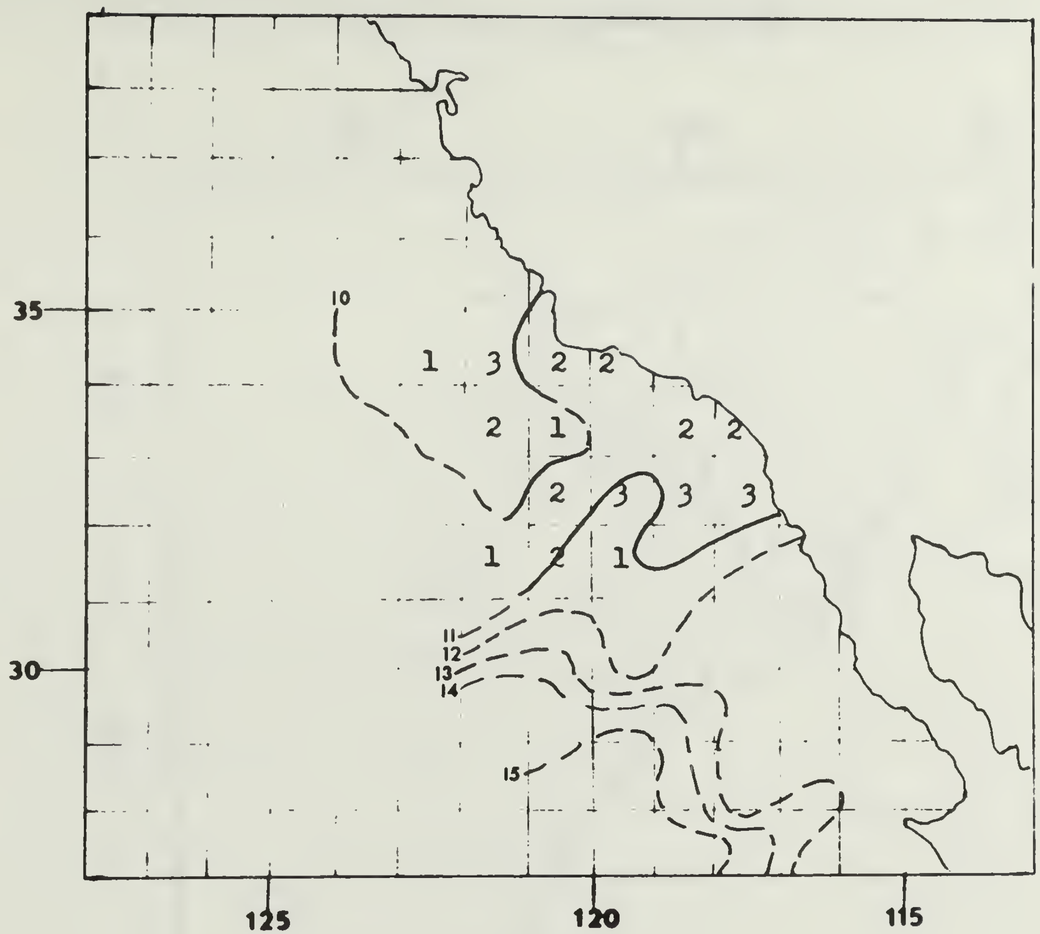
Figure 40a.



November 1959

10-meter level isotherms

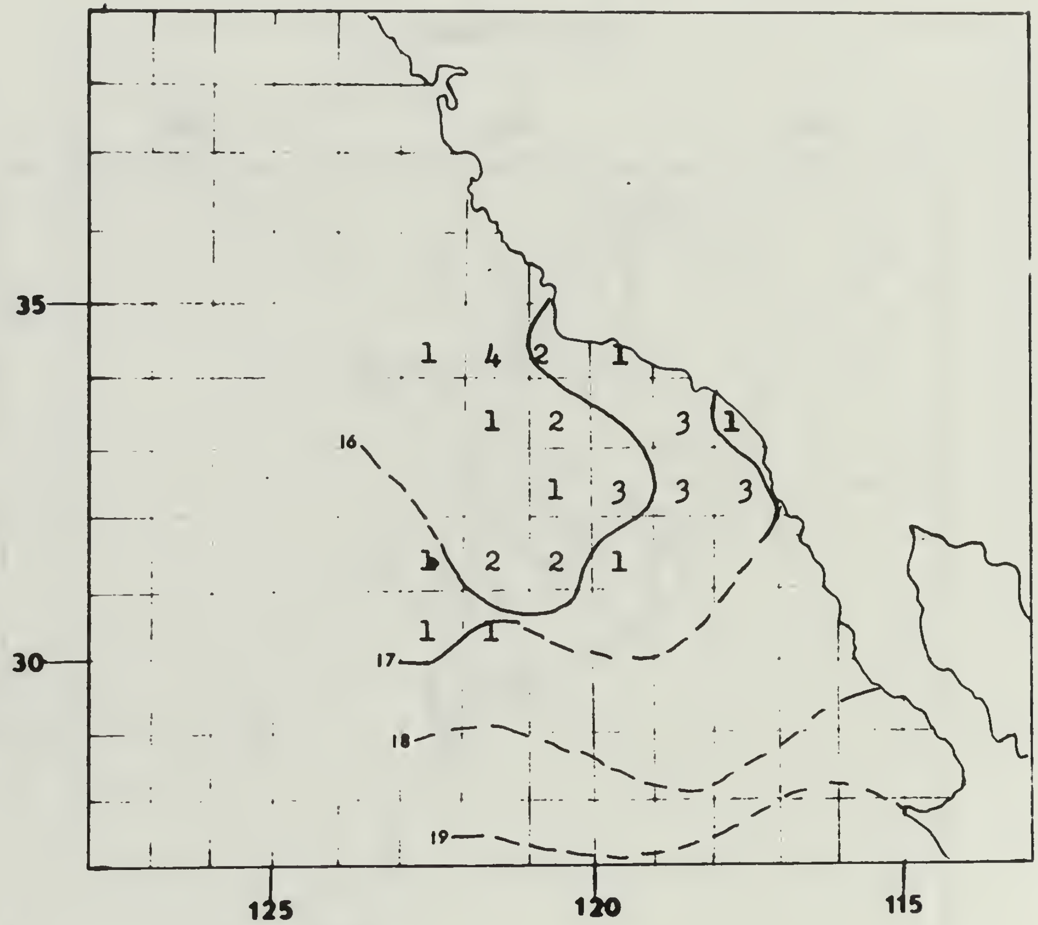
Figure 40b.



November 1959

100-meter level isotherms

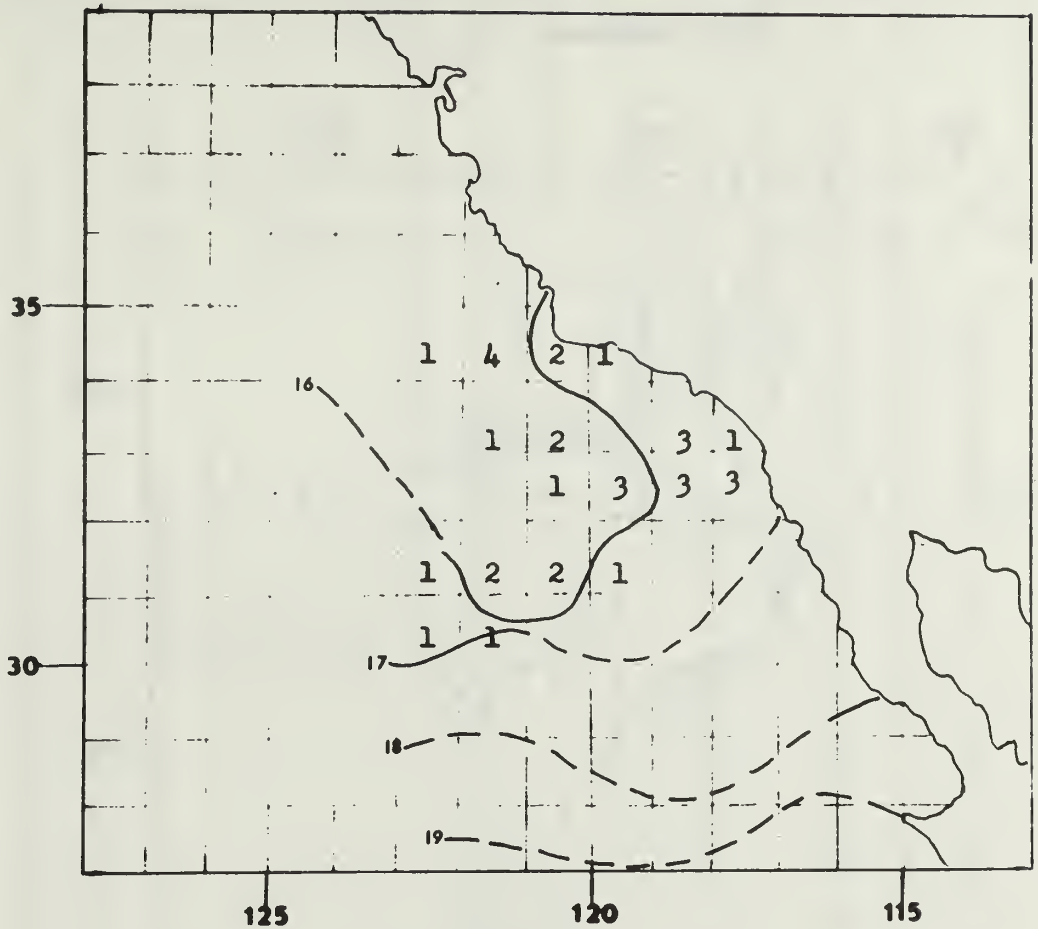
Figure 40e.



December 1959

Surface isotherms

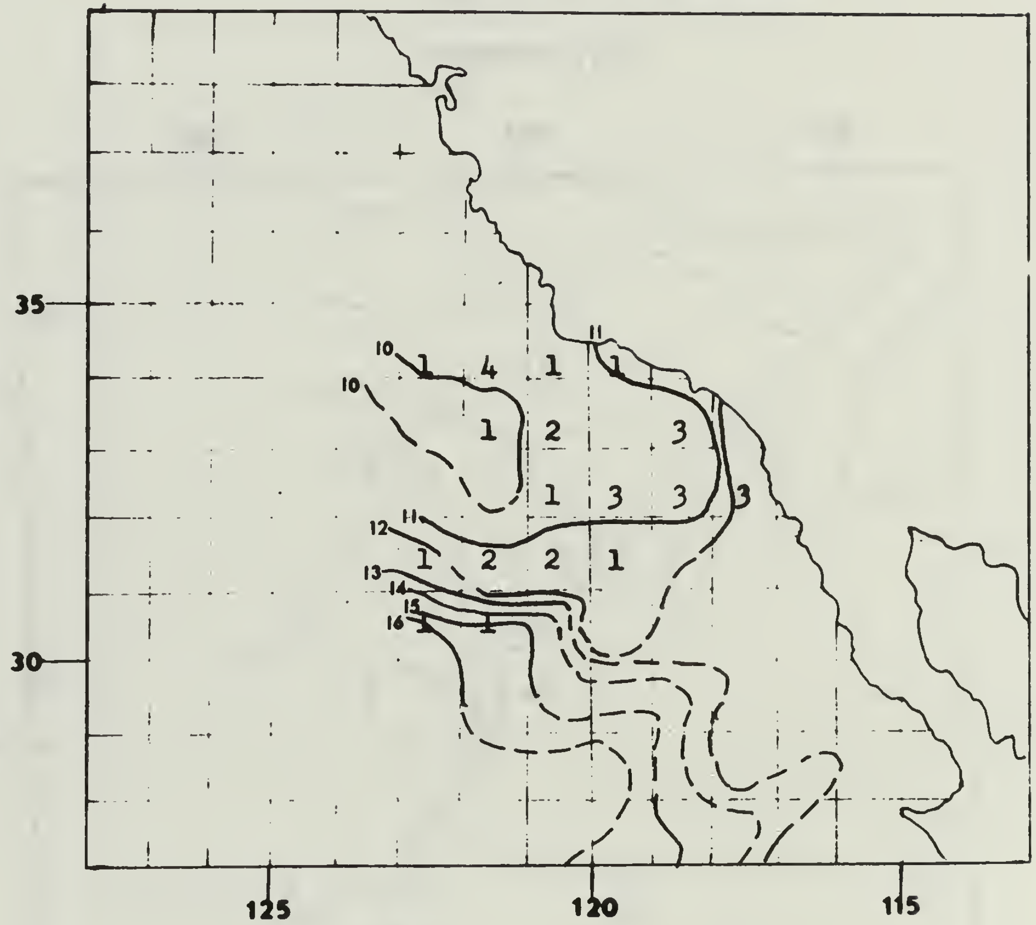
Figure 41a.



December 1959

10-meter level isotherms

Figure 41b.



December 1959

100-meter level isotherms

Figure 41c.

IV. EVALUATION

Current analysis of temperature and density structure employ various forms of data smoothing techniques (Lynn, 1967; Griswold et al., 1968). It is current practice to utilize data collected over a period of years and then to average these data over monthly or seasonal periods.

This study has utilized averaged data on a synoptic basis from scientific expeditions only. Although data density is less than that of computerized environmental prediction systems, the data are assumed to be essentially correct.

The internal wave effect is assumed to be negligible by virtue of the averaging processes employed.

A. DATA DISTRIBUTION

Based on the available data the following months are assumed to have sufficient data for complete analysis.

1.

January 1958	January 1959
April 1958	April 1959
July 1958	July 1959
	August 1959
October 1958	October 1959

2. Analyses of temperature structure for other months were prepared from available data and temperature structures extrapolated from months in (1).

B. 100-METER TEMPERATURE STRUCTURE

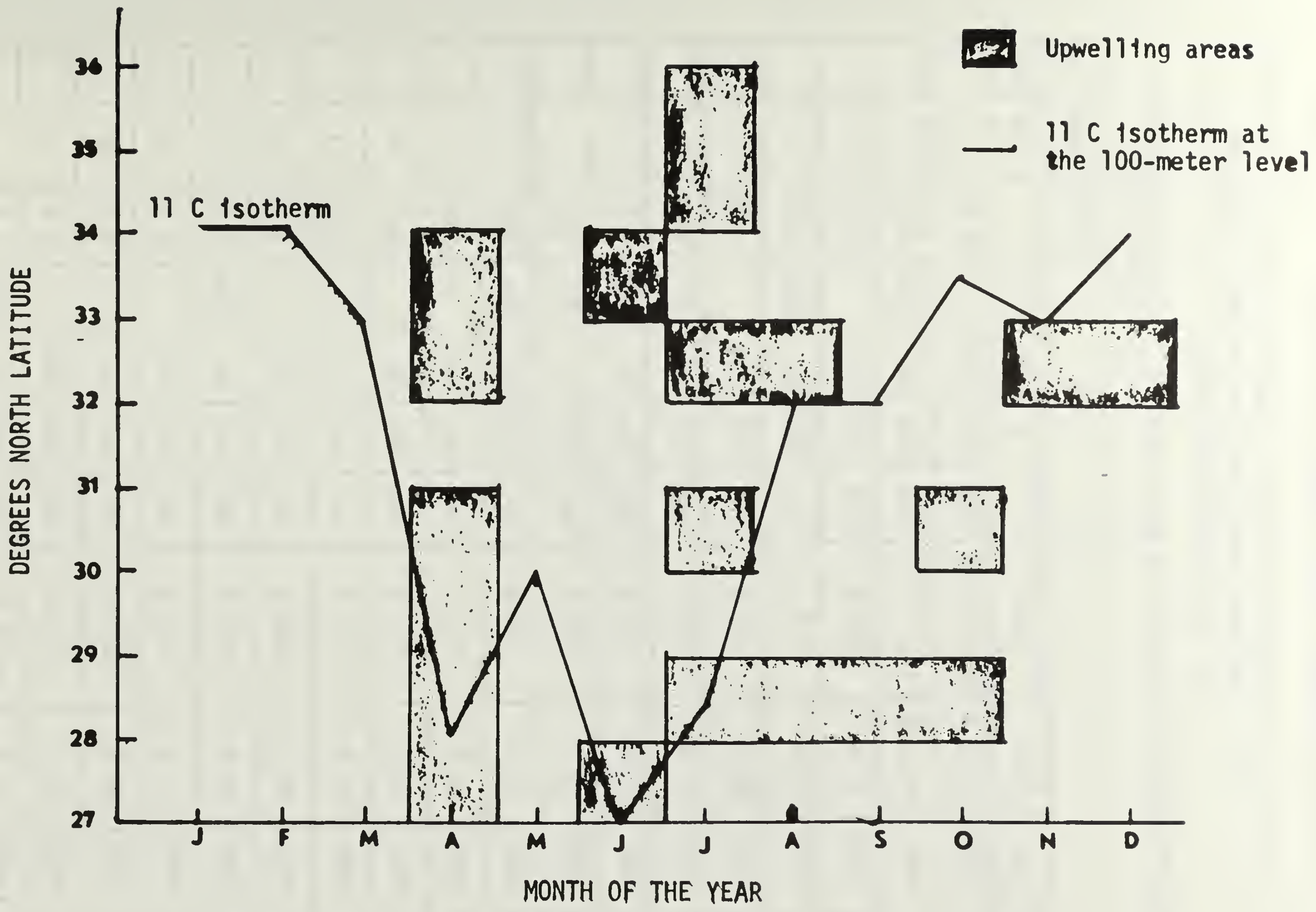
Upon close examination of the 100-meter temperature structure, a definite pattern seems to be present, especially in the behavior of the 11 C isotherm. A plot of the 11 C isotherm's position was superimposed upon a plot of possible upwelling areas based on surface temperature alone (see Fig. 42).

As the 11 C isotherm progressed from 34 N to lower latitudes, upwelling appeared to begin in the month of April. In June when the isotherm reached its lowest limit of 27 N, upwelling areas are prevalent along most of the coast line (27 N - 36 N). As the isotherm started to recede to higher latitudes upwelling areas are still indicated as low as 29 N. Since upwelling is a relatively slow process, it could, in theory, have a slow decay period and still show in signs of upwelling at the surface and 10-meter level, while it had abated at the 100-meter level. A three-month lag is suggested here.

Fenner (1965) showed that slight upwelling can indeed be present at depths and not necessarily be detected at the surface by a decrease in temperature. Consequently the upwelling criteria that has been set forth in Section III (B), may indicate the true start and end of upwelling.

C. ANALYSIS OF UPWELLING AREAS

The procedure used to determine if an area was in a state of upwelling follows the four criteria set forth in Section II (C). In addition to these criteria it was attempted to further distinguish mature upwelling areas from those areas that showed signs of upwelling decay or only a shallow layer upwelling phenomenon. Results of this analysis are summarized in Table 3.



Correlation between 11 C isotherm at 100-meter level and upwelling areas

Figure 42

Table 3

Evaluation of Possible Upwelling Areas

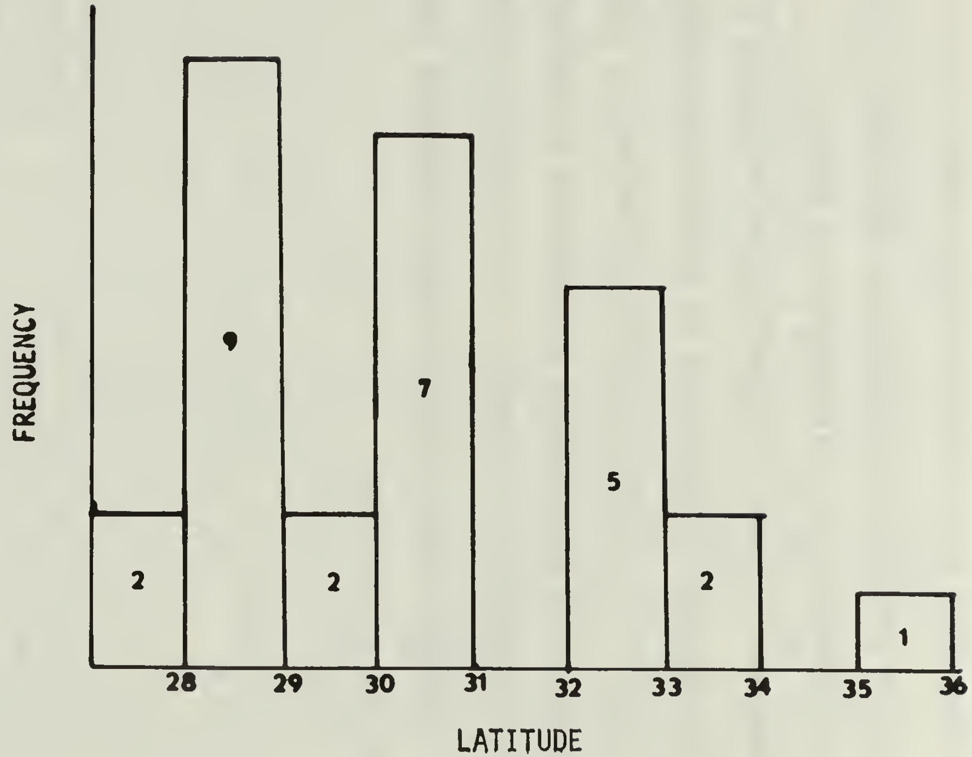
x -- indicates definite upwelling
* -- indicates upwelling has probably occurred and is in a state of decay

				Criteria Satisfied						
				IIC				IIIB	Upwelling	
Month	Year	Lat.	Long.	1	2	3	4		Yes	No
April	1958	33-34 N	120-121 W	Yes	Yes	Yes		N.A.	x	
April	1958	29-30 N	115-116 W	Yes	Yes	No	Yes	N.A.	x	
June	1958	34 N	120 W	Yes	Yes	Yes		N.A.	x	
July	1958	29 N	115 W	Yes	Yes	No	Yes	N.A.	x	
July	1958	36 N	122 W	Yes	Yes	Yes		N.A.	x	
July	1958	31 N	116 W	Yes	Yes	Yes		N.A.	x	
Aug.	1958	29 N	115 W	Yes	Yes	No	Yes	N.A.	x	
Sept.	1958	29 N	115 W	Yes	Yes	No	Yes	Yes	*	
Oct.	1958	31 N	116 W	Yes	Yes	No	Yes	Yes	*	
Nov.	1958	33 N	117 W	Yes	Yes	Yes		Yes	*	
Dec.	1958	33 N	117 W	Yes	Yes	No		Yes	*	
April	1959	29 N	115 W	Yes	Yes	Yes		N.A.	x	
April	1959	34 N	120 W	Yes	Yes	Yes		N.A.	x	
June	1959	28 N	116 W	Yes	Yes	No	Yes	N.A.	x	
July	1959	31 N	116 W	Yes	Yes	Yes		N.A.	x	
July	1959	35 N	121 W	Yes	Yes	Yes		N.A.	x	
Aug.	1959	33 N	117 W	Yes	Yes	Yes		N.A.	x	
Aug.	1959	31 N	116 W	Yes	Yes	No	Yes	N.A.	x	
Sept.	1959	29 N	115 W	Yes	Yes	Yes	Yes	Yes	*	
Oct.	1959	31 N	116 W	Yes	Yes	No	Yes	Yes	*	
Oct.	1959	29 N	115 W	Yes	Yes	No	Yes	Yes	*	

Based on Table 3, upwelling areas were plotted by latitude to determine if there were any preferred locations for upwelling during the years 1958-1959 (see Figures 43 and 44).

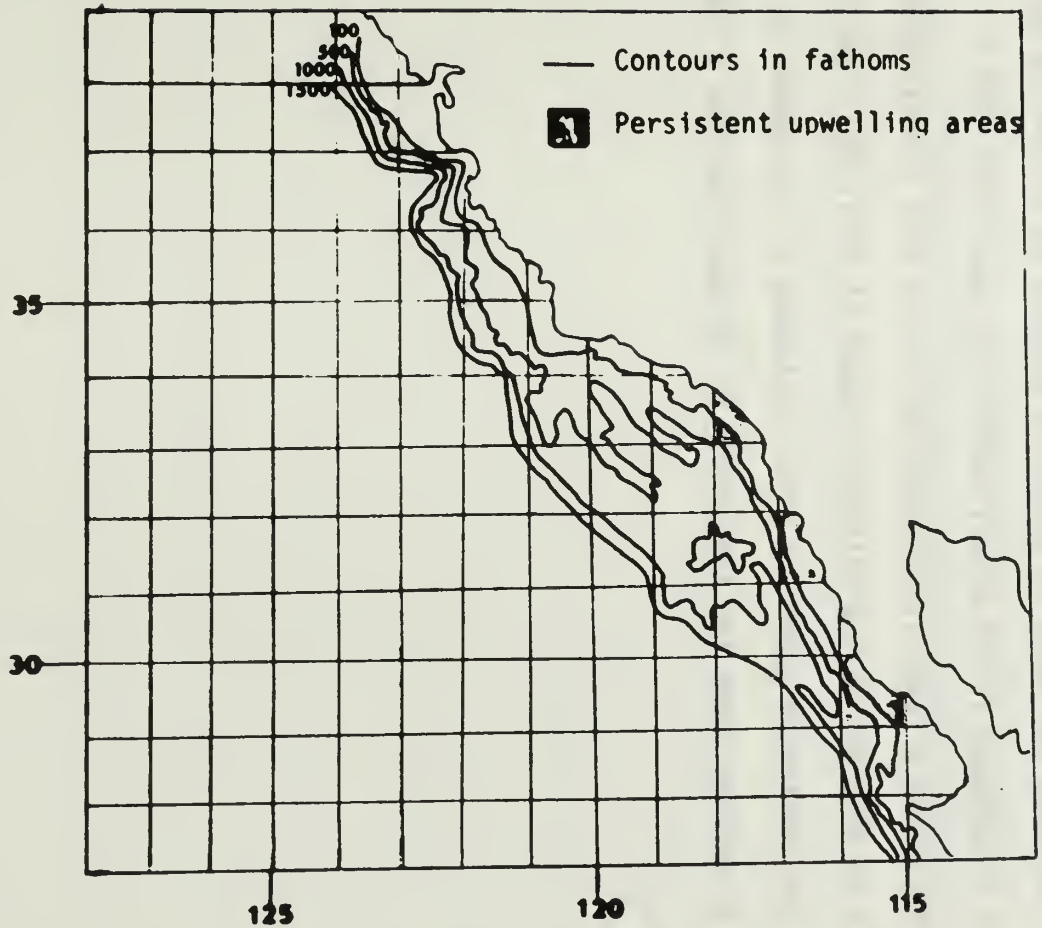
The general pattern of upwelling as described by Reid (1958) is in good agreement with Fig. 42, although it appears to indicate that the onset of upwelling starts almost simultaneously in April between 27-34 N. Fig. 44 indicates the most persistent areas of upwelling to be where the continental shelf gradient is great.

It is uncertain if areas of probable upwelling decay as analyzed in Table 3 are valid or if conditions of a cold water pocket exist in the area of 29 N in the winter months as proposed by Lynn (1967). Further analysis would be necessary to determine the variability of the temperature and density structure in this area on a synoptic basis. It is possible that these conditions could vary considerably from year to year in this area.



Upwelling areas, frequency-latitude analysis

Figure 43



Persistent upwelling areas along the California coast

Figure 44

V. CONCLUSIONS

The prepared sections of temperature at the surface, 10-meter and 100-meter levels provide indications of temperature variations which effect monthly upwelling patterns. The following conclusions resulted from these indications.

1. High accuracy, lower data density synoptic temperature field analysis can detect probable upwelling areas.

2. The onset and decay of upwelling appears to follow the path of the 11 C isotherm at 100 meters during the years 1958-1959.

3. The areas of persistent upwelling during this investigation appear to be adjacent to the California coast at 29 N, 31 N, and 33 N.

4. The persistent upwelling areas indicated in (3) appear to be located in regions where the topography of the sea floor has a steep gradient.

VI. RECOMMENDATIONS FOR FURTHER RESEARCH

Measurements of temperature and density structure on an accurate basis are needed to analyze systematically the complex system of upwelling along the California coast.

An extensive buoy array measuring temperature and salinity along the California coast while being initially expensive would be far more meaningful than present data collecting techniques.

A detailed study of topography off the coast of California correlating continental shelf features with persistent upwelling areas would be of value.

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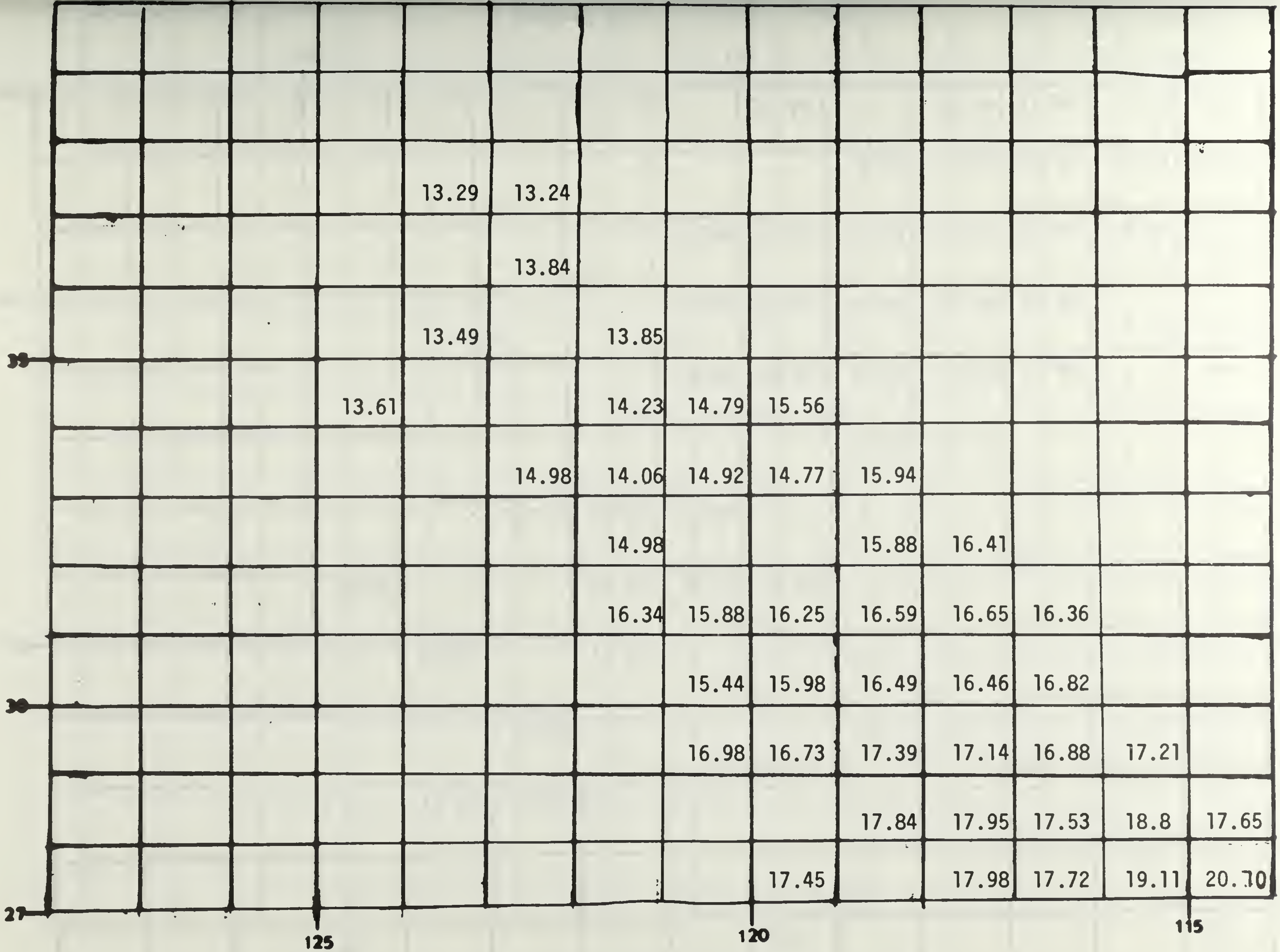
APPENDIX A



January 1958 - Surface Isotherms

				13.28	13.24								
					13.83								
				13.50		13.74							
			13.62			14.22	14.78	15.38					
					14.99	14.06	14.84						
									15.89	16.36			
							15.89	16.26	16.43	16.68	16.37		
							15.44	15.87	16.43	16.44	16.87		
							16.98	16.75	17.37	17.16	16.90	17.26	
									17.80	17.99	17.40	18.82	17.67
								17.43		18.00	17.66	19.18	20.12

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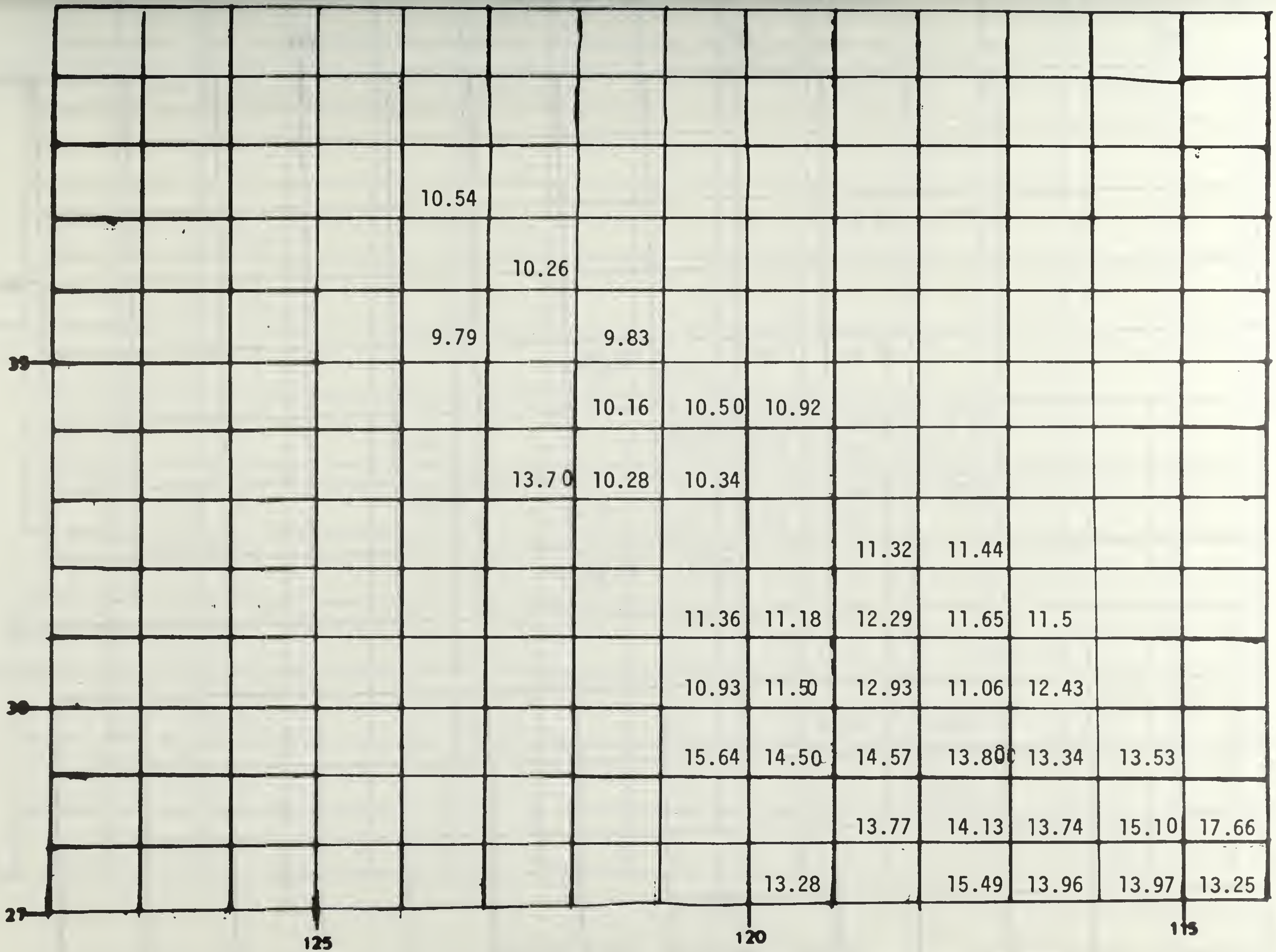
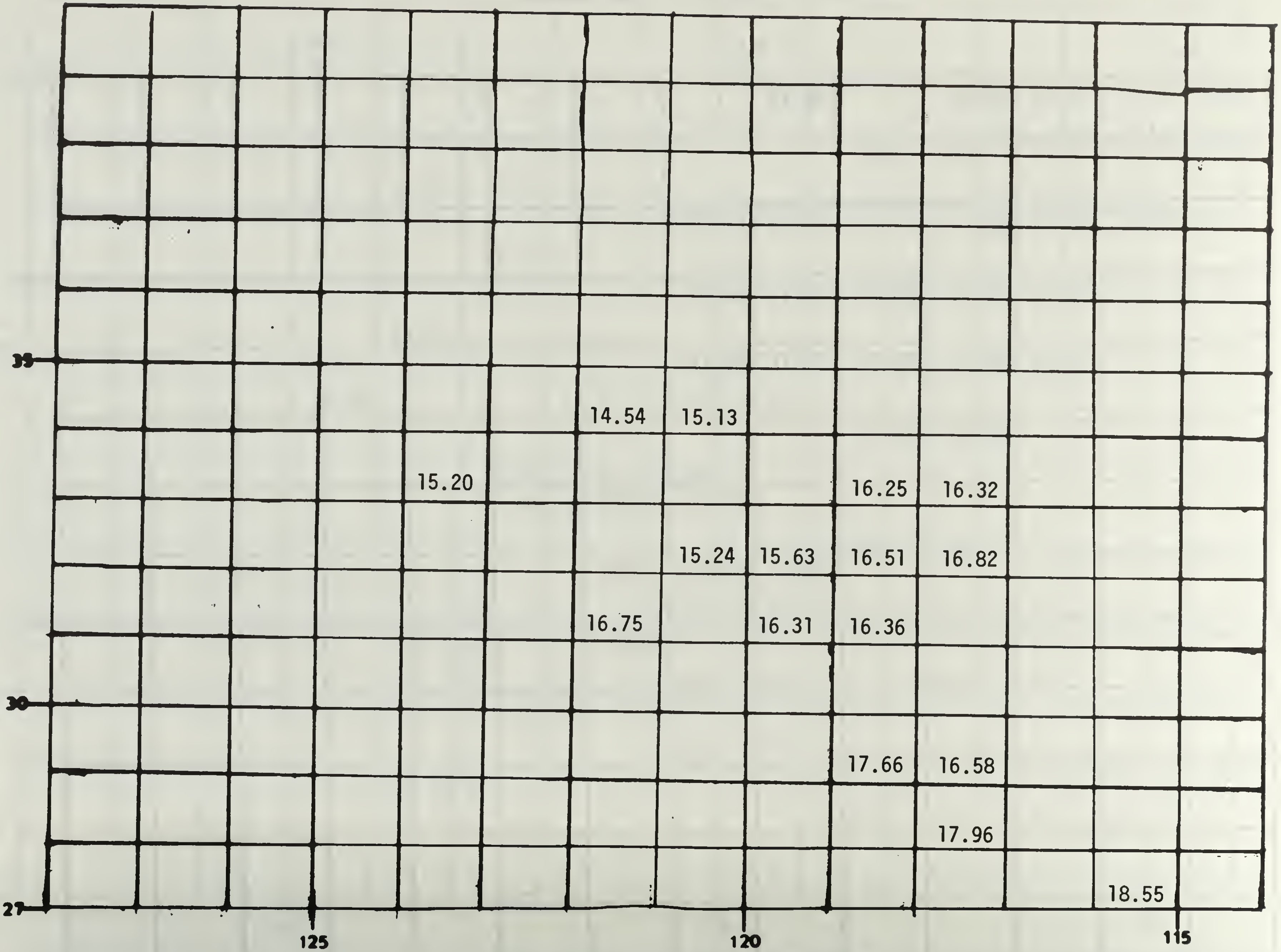
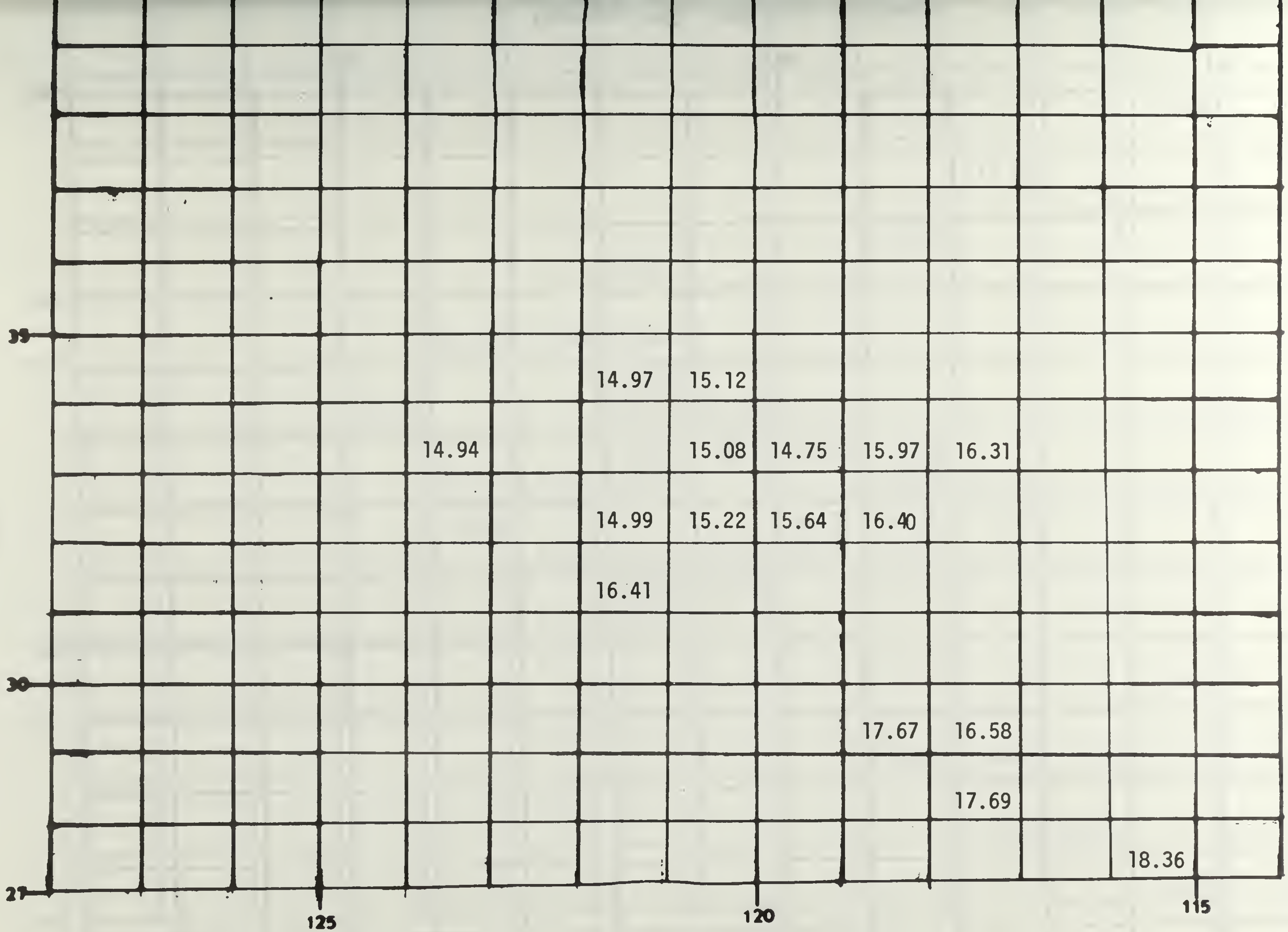
January 1958 - 10 Meter Isotherms



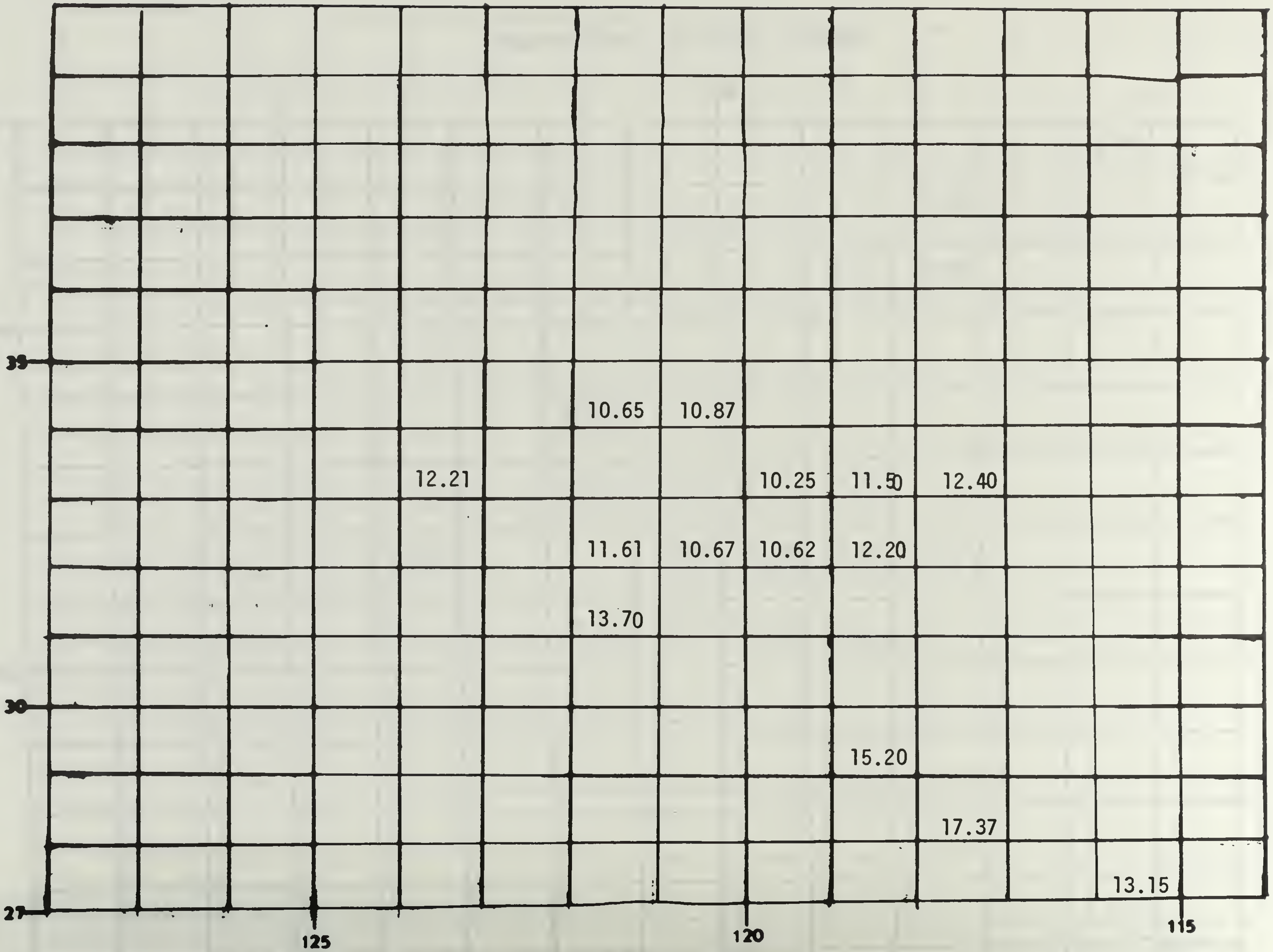
January 1958 - 100 Meter Isotherms



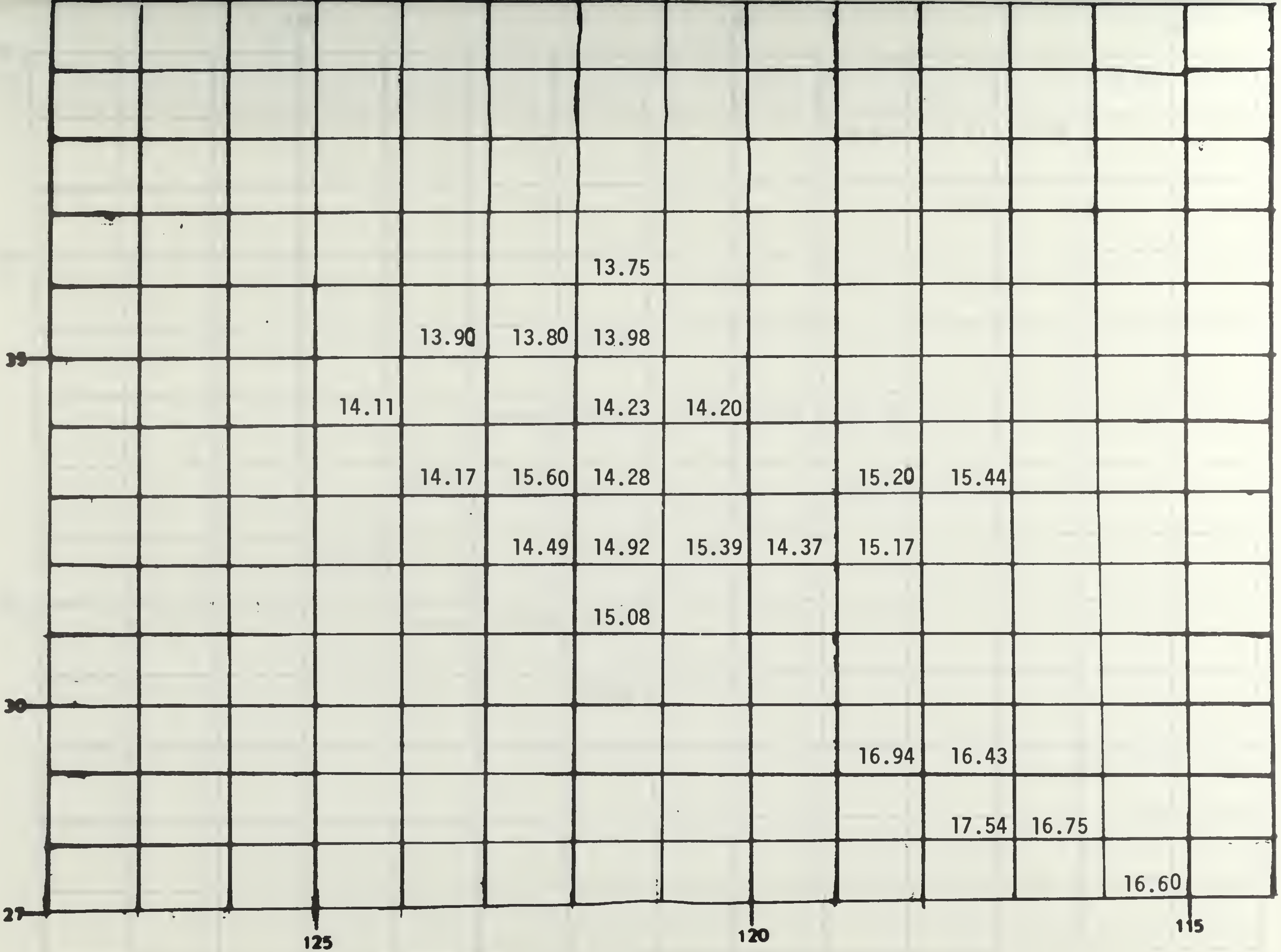
February 1958 - Surface Isotherms



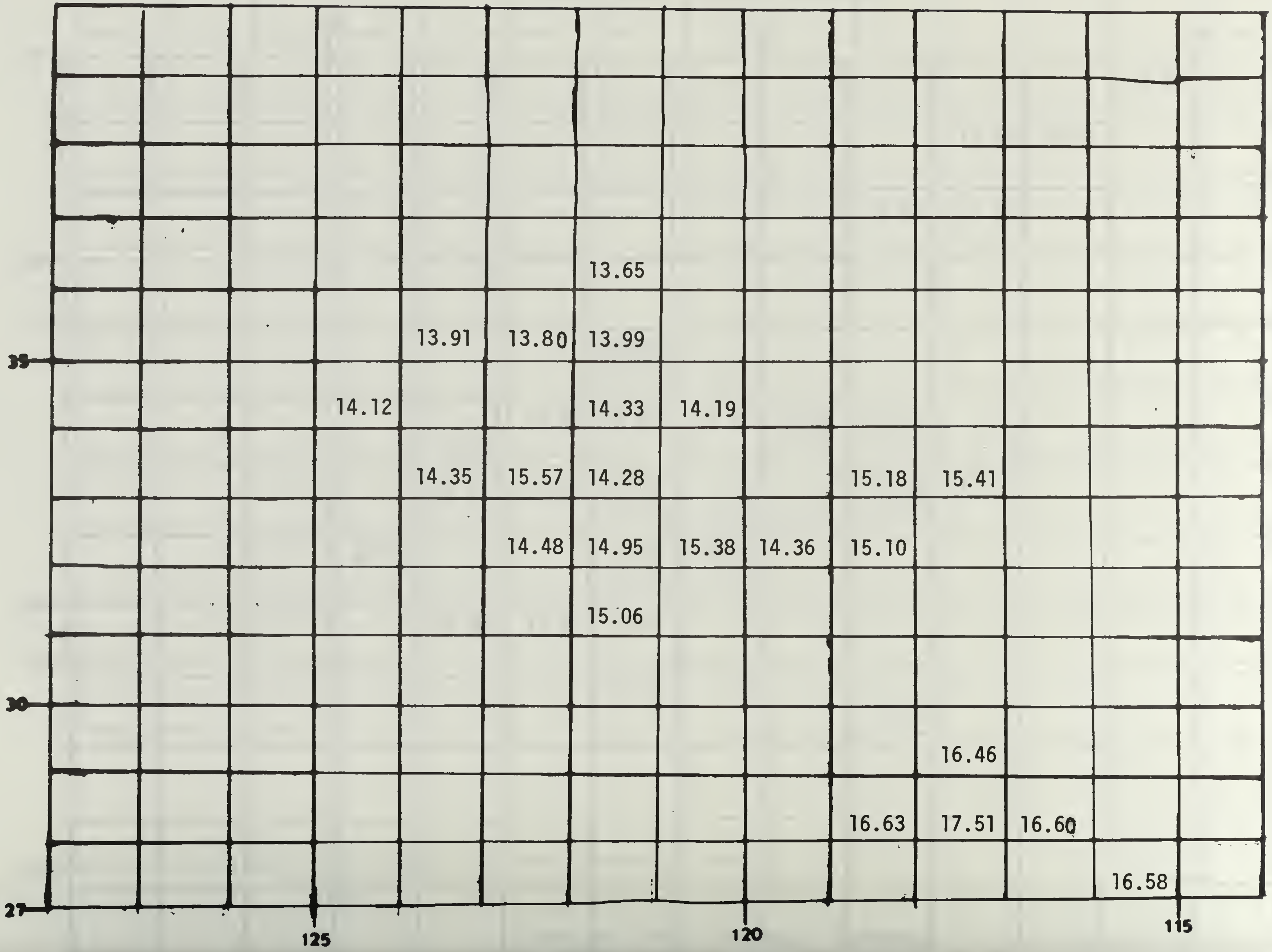
February 1958 - 10 Meter Isotherms



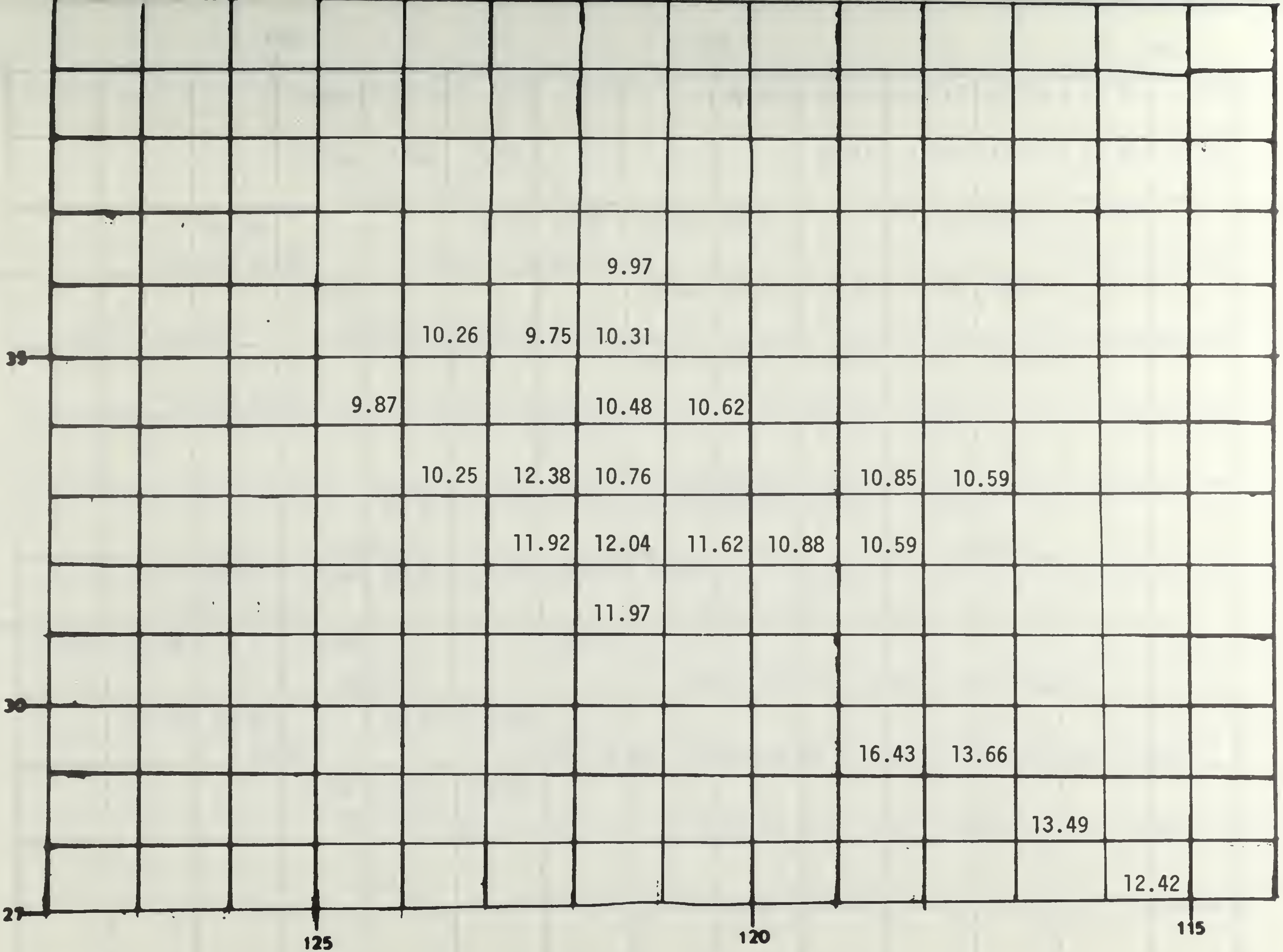
February 1958 - 100 Meter Isotherms



March 1958 - Surface Isotherms



March 1958 10 Meter Isothe



March 1958 - 100 Meter Isotherms

			13.31	13.28	13.92								
	13.39	13.46		13.22	13.98								
14.68	14.94		13.88			14.12							
		14.01	14.05	14.33	14.12	13.86	13.81						
				15.08	14.23	13.91	14.93	14.40	15.12	15.79			
						15.38			15.67	18.12			
							16.19	16.45	16.92	17.54	17.50		
			16.94				16.20	16.24	16.76	17.36	16.89		
		17.39			18.18	16.66	17.03	16.61		17.13	17.24	16.50	
			18.84	17.79	17.72				17.51	17.02	17.42	17.25	16.70
			17.86					18.40	18.17	18.10	17.40	17.47	17.94

35 30 27

125 120 115

April 1958 - Surface Isotherms

			13.23	13.22	13.16								
	13.40	13.39		13.22	13.96	13.46							
14.57	14.86		13.88	13.80	13.58	13.63							
	14.40	13.98	14.09	14.29	14.15	13.72	13.77	14.90					
				15.06	14.22	13.89	14.46	14.38	15.03	15.82			
			14.54			15.38			15.64	16.84			
	15.56	15.33					16.14	16.26	16.70	16.44	17.13		
			16.92				16.12	16.20	16.77	17.27	16.82		
		17.37			17.18	16.58	17.05	16.59	17.20	17.13	17.25	16.48	
			18.27	17.80	17.54		17.50	17.79	17.52	16.89	17.33	17.08	16.65
			17.74					18.39	18.17	18.11	17.40	17.47	17.88

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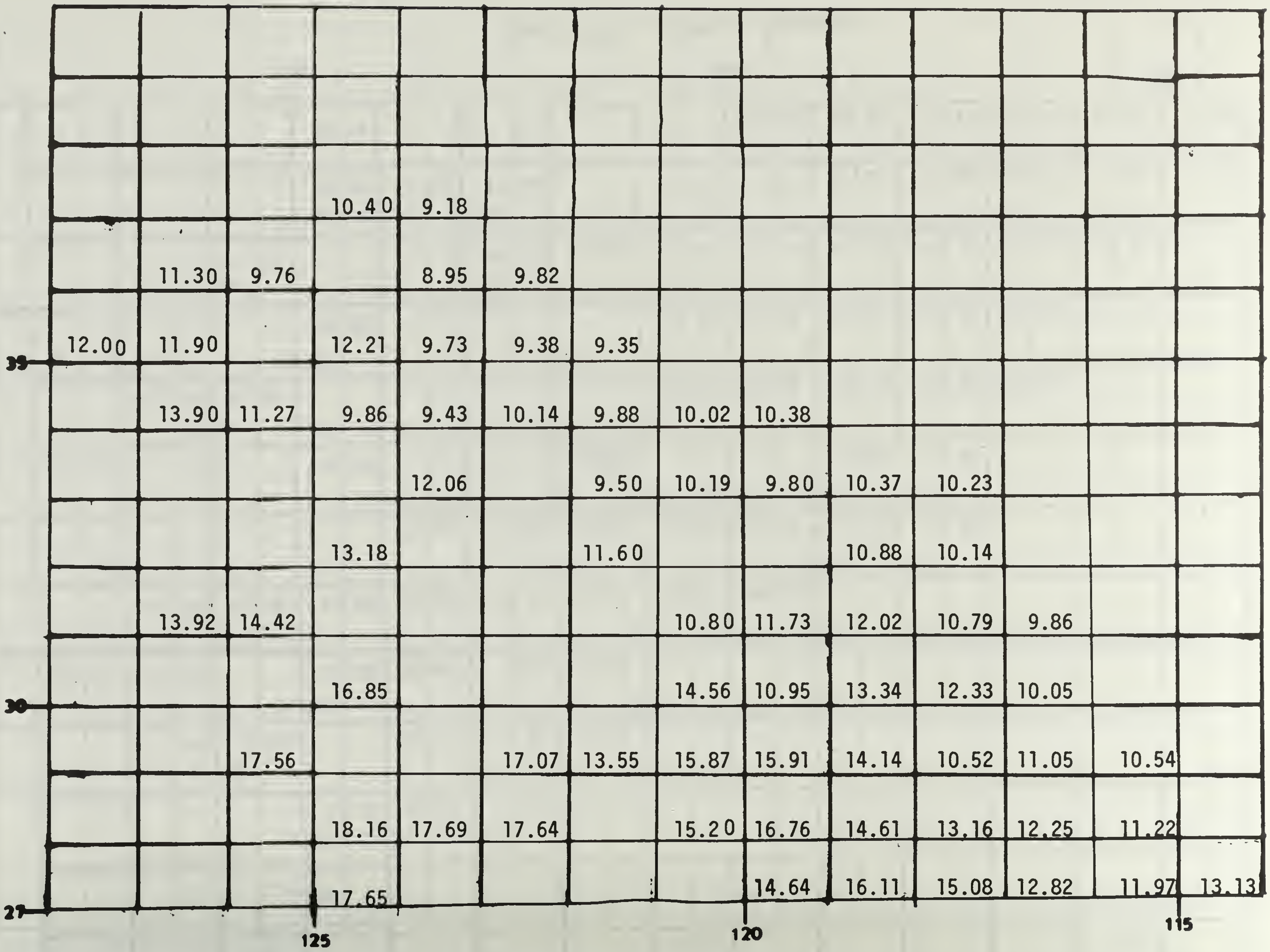
April 1958 - 10 Meter Isotherms



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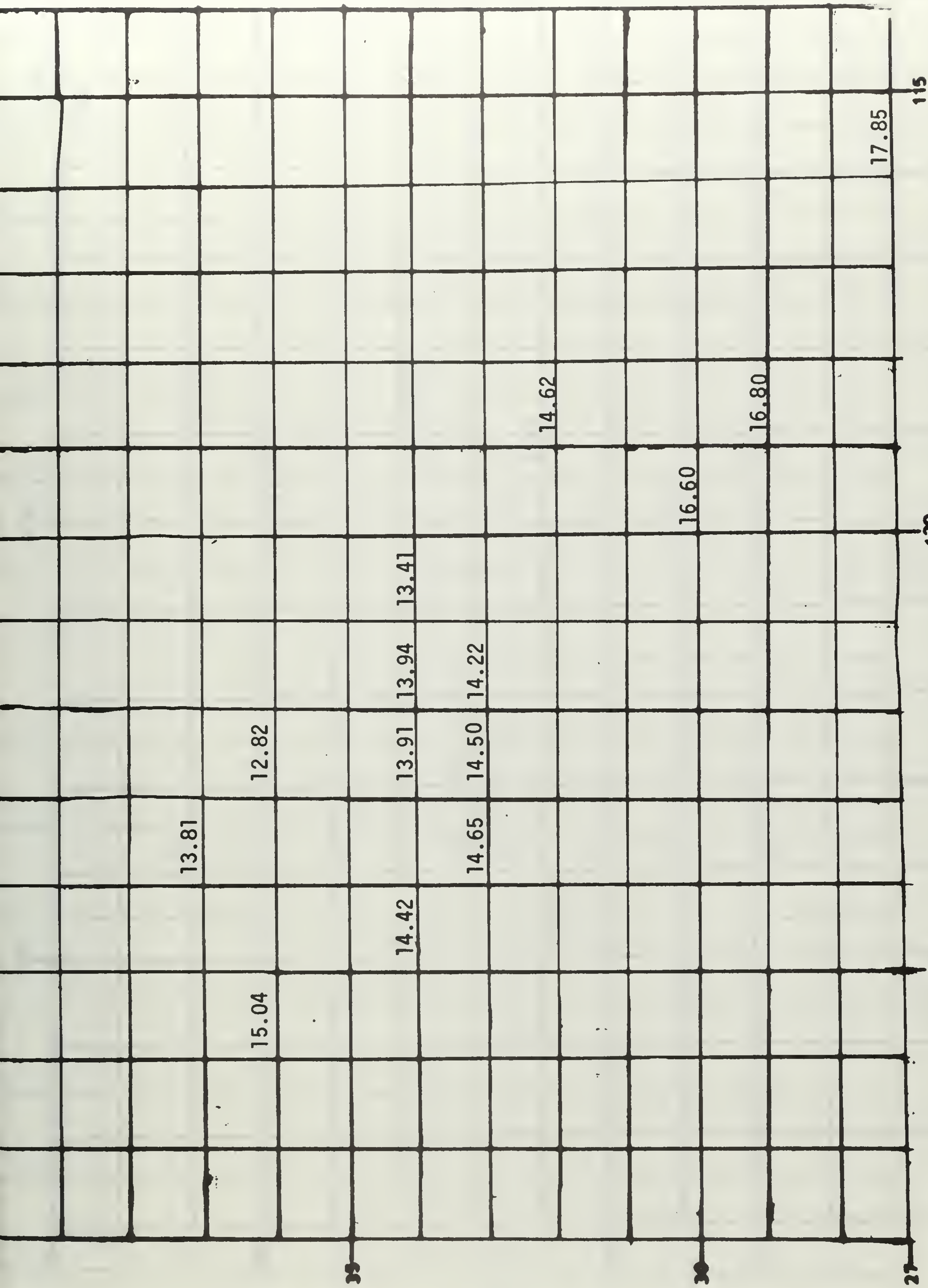
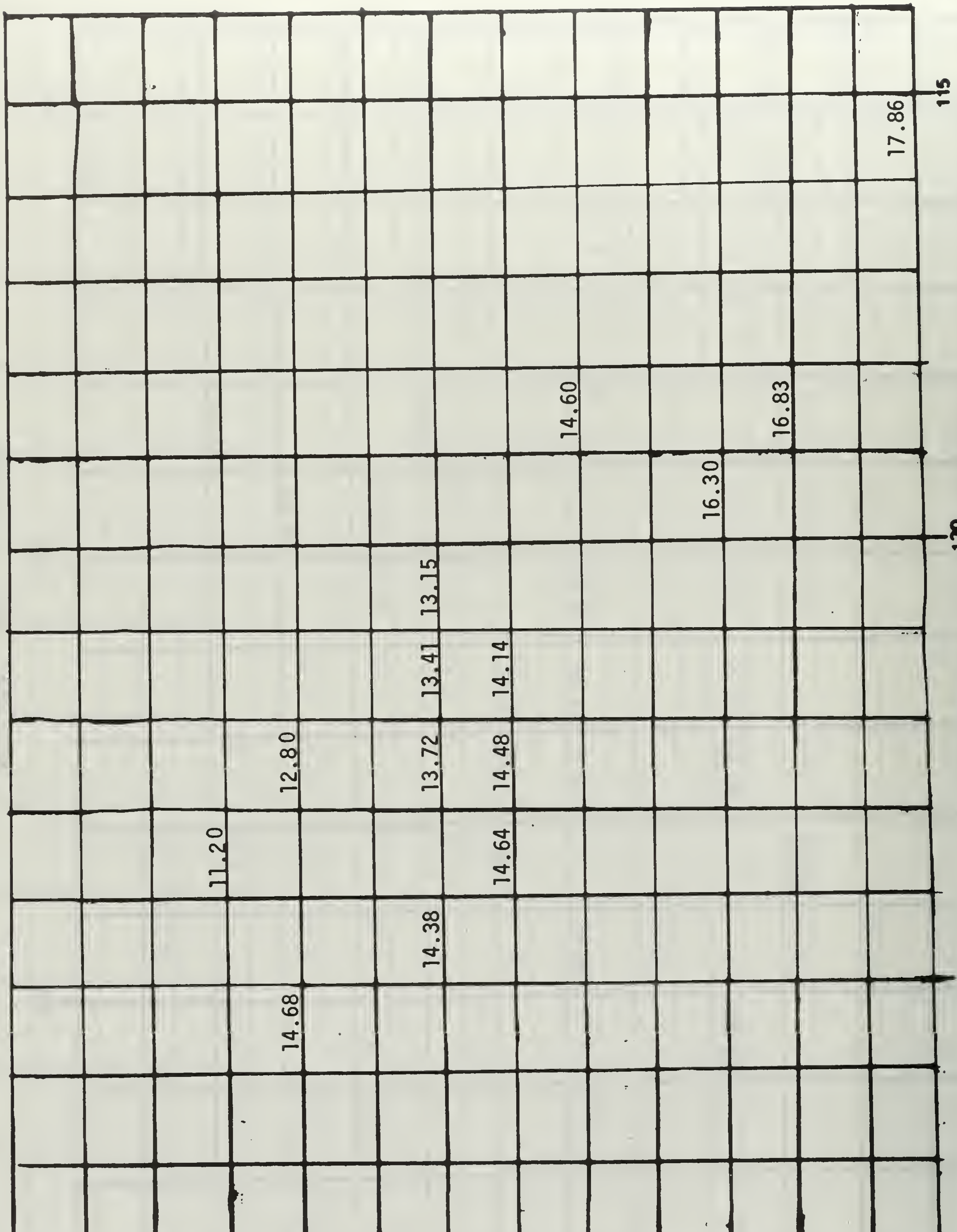


May 1958 - Surface Isotherms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12.80
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11.20
14.64
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14.68
115
120
125
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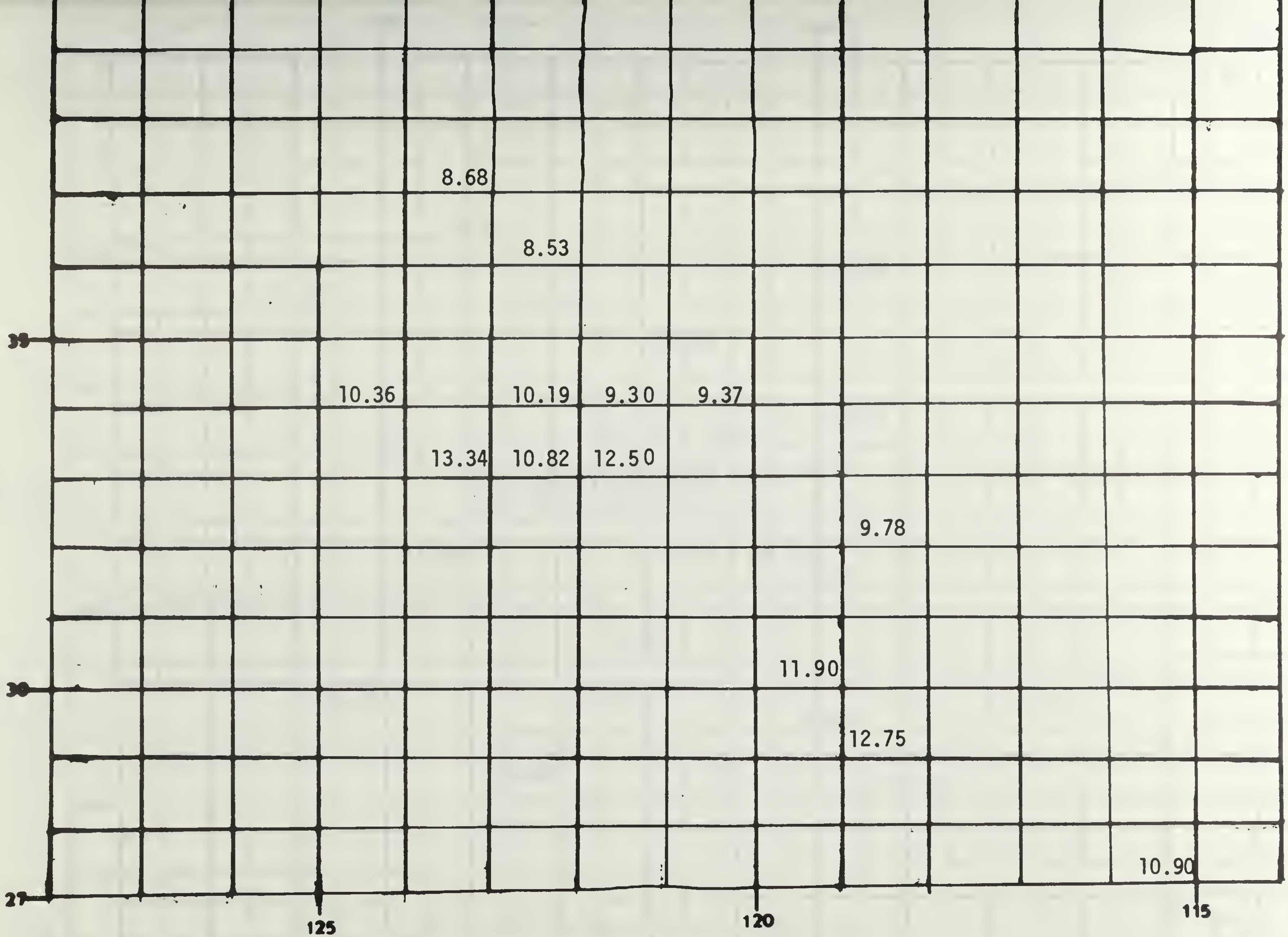
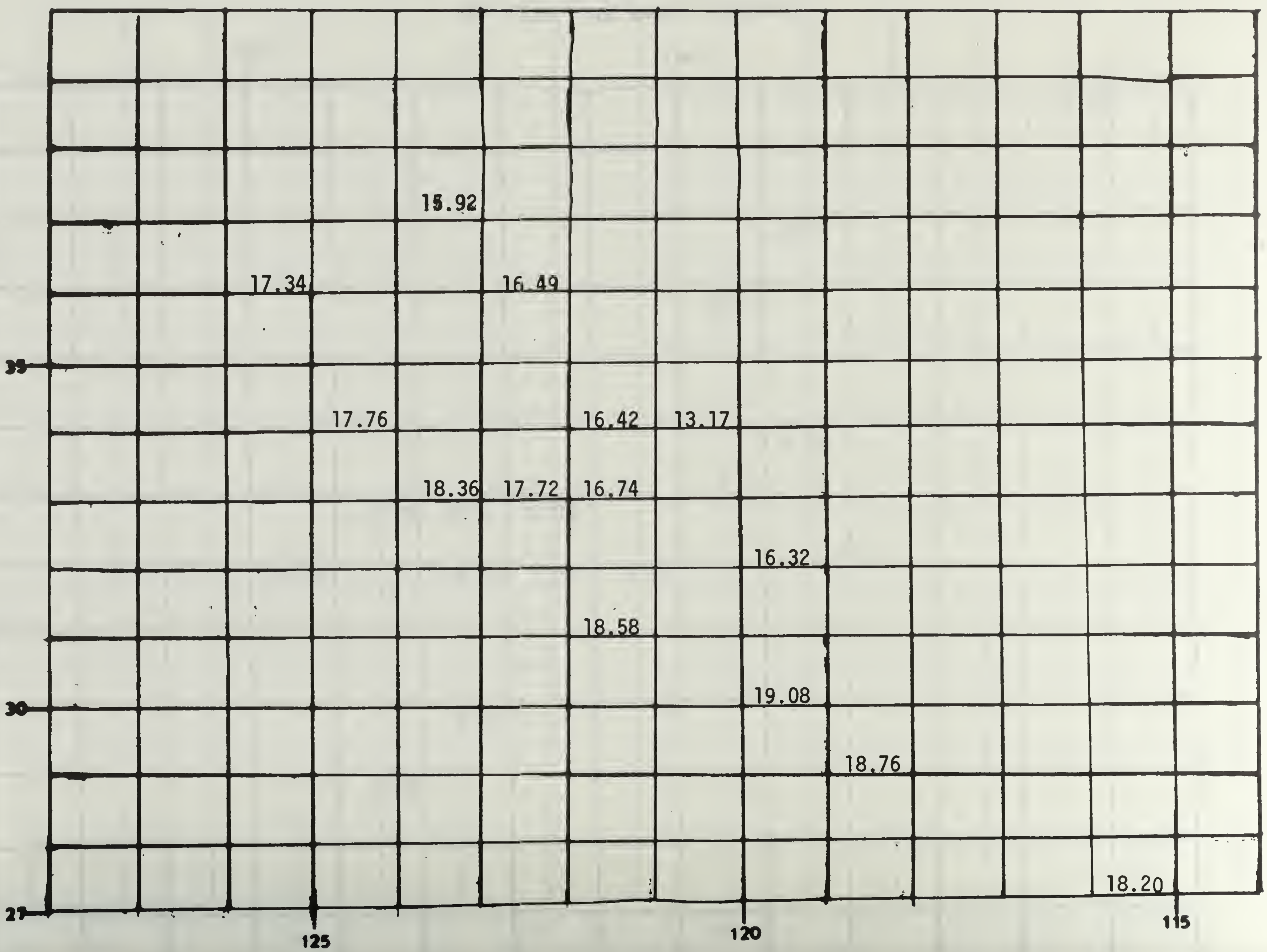
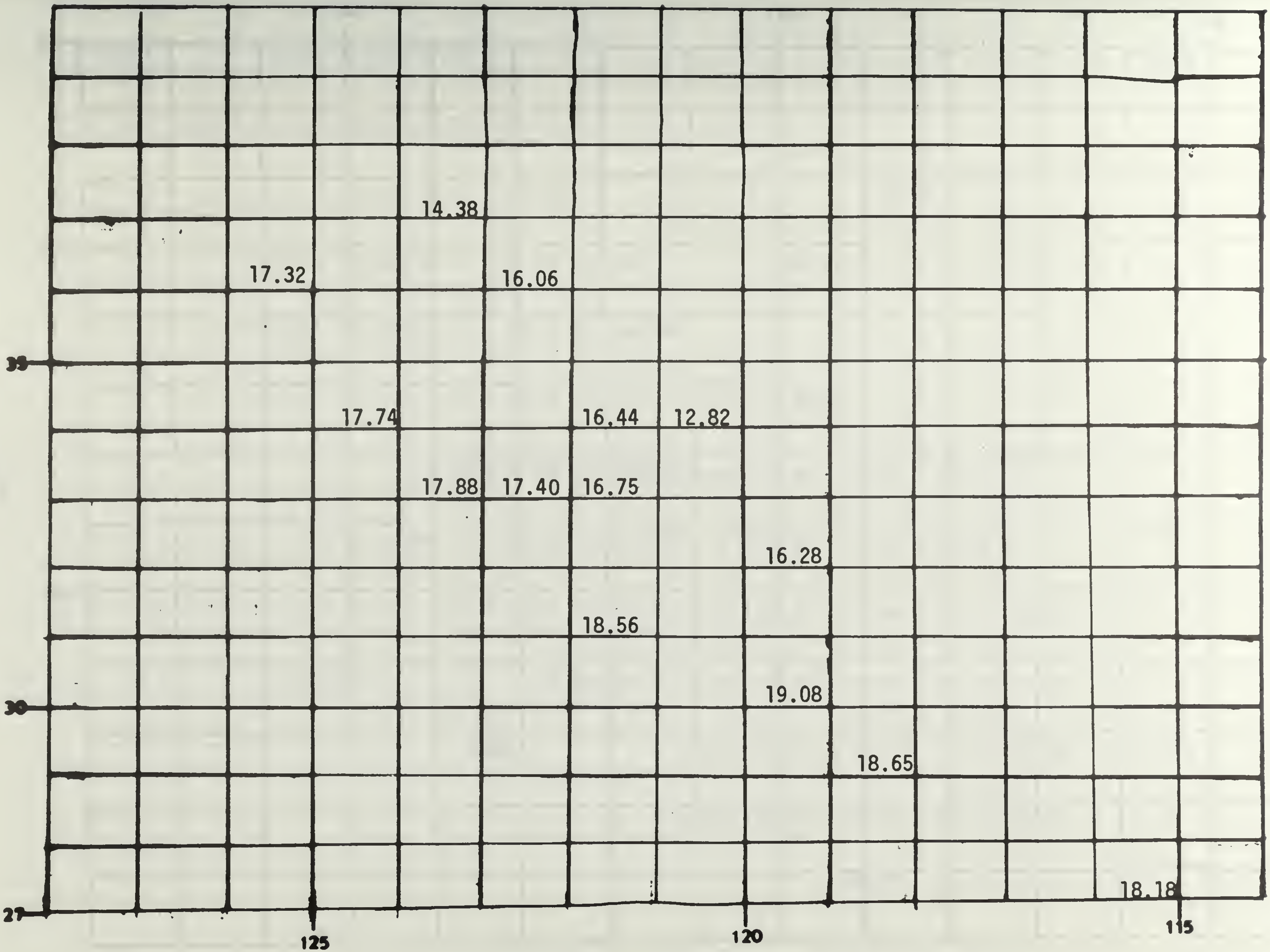


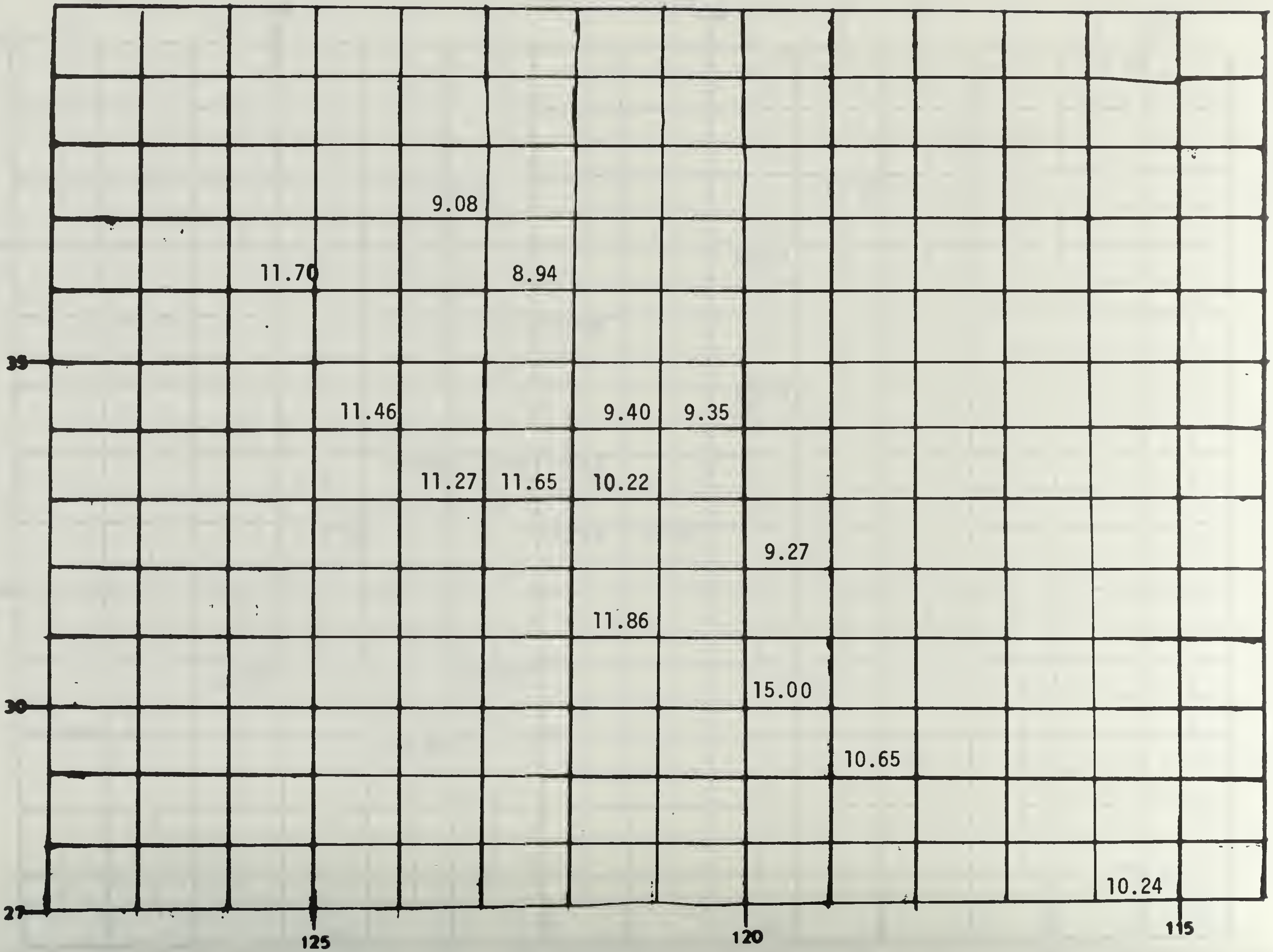
May 1958 - 100 Meter Isotherms



June 1958 - Surface Isotherms



June 1958 - 10 Meter Isotherms



June 1958 - 100 Meter Isotherms

16.68		15.00	15.20	11.84									
17.00	16.52		13.11	12.33									
			15.27	14.41	12.81								
		16.32	16.05	16.17	11.91	11.88							
		17.38	17.38	16.21	15.65	12.57							
		17.75	17.14	16.52	16.69	14.23	13.08	15.23					
				17.98	17.58	16.92	14.64	17.84	19.87	20.77			
					18.34	18.14		16.46	17.27	20.01			
					18.71	18.10	17.28	16.42	17.44	17.97	17.40		
						18.94	19.29	18.44	18.86	18.74	18.16		
							19.85	19.73	19.67	19.30	17.86	15.72	
							20.16	19.68	20.55	19.75	18.50	18.89	18.56
									20.55	20.90	19.20	20.70	19.45

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July 1958 - Surface Isotherms

16.99	16.50		11.32	11.58									
			15.24	14.39	11.05								
		16.31	16.05	16.15	11.87	11.86							
		17.39	17.38	16.20	15.17	12.47							
		17.76	17.10	16.44	16.71	14.20	12.98	14.66					
				17.98	17.60	16.90	13.86	11.51	16.65	18.60			
					18.06	18.15		15.47	16.97	17.31			
					18.71	17.95	17.26	16.37	17.40	17.85	15.93		
						18.94	19.27	18.37	18.88	18.55	17.53		
							19.84	19.96	19.56	19.29	17.40	15.07	
							19.97	19.63	20.25	19.71	18.52	18.86	18.55
									20.56	20.87	19.24	20.66	19.47

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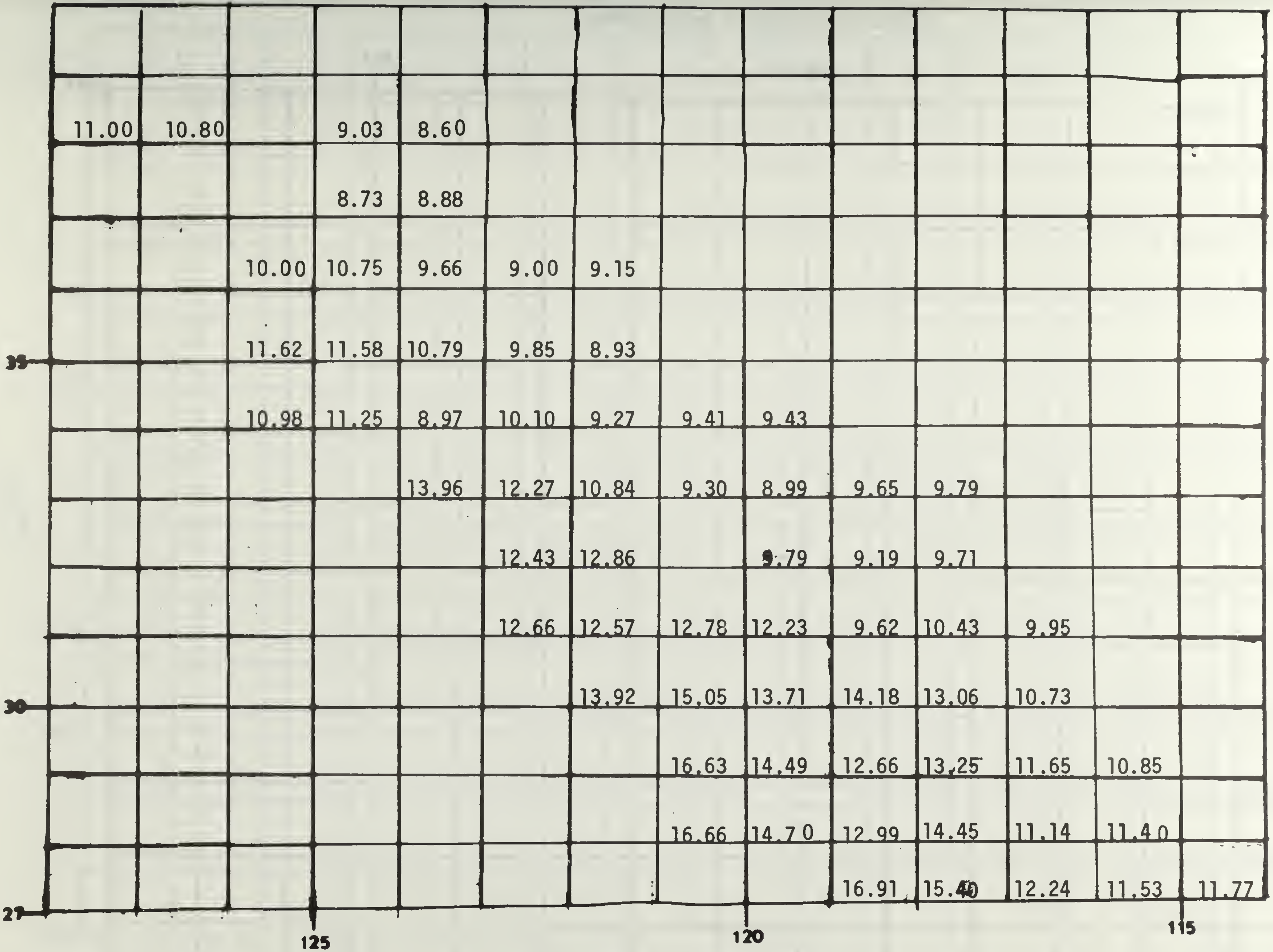
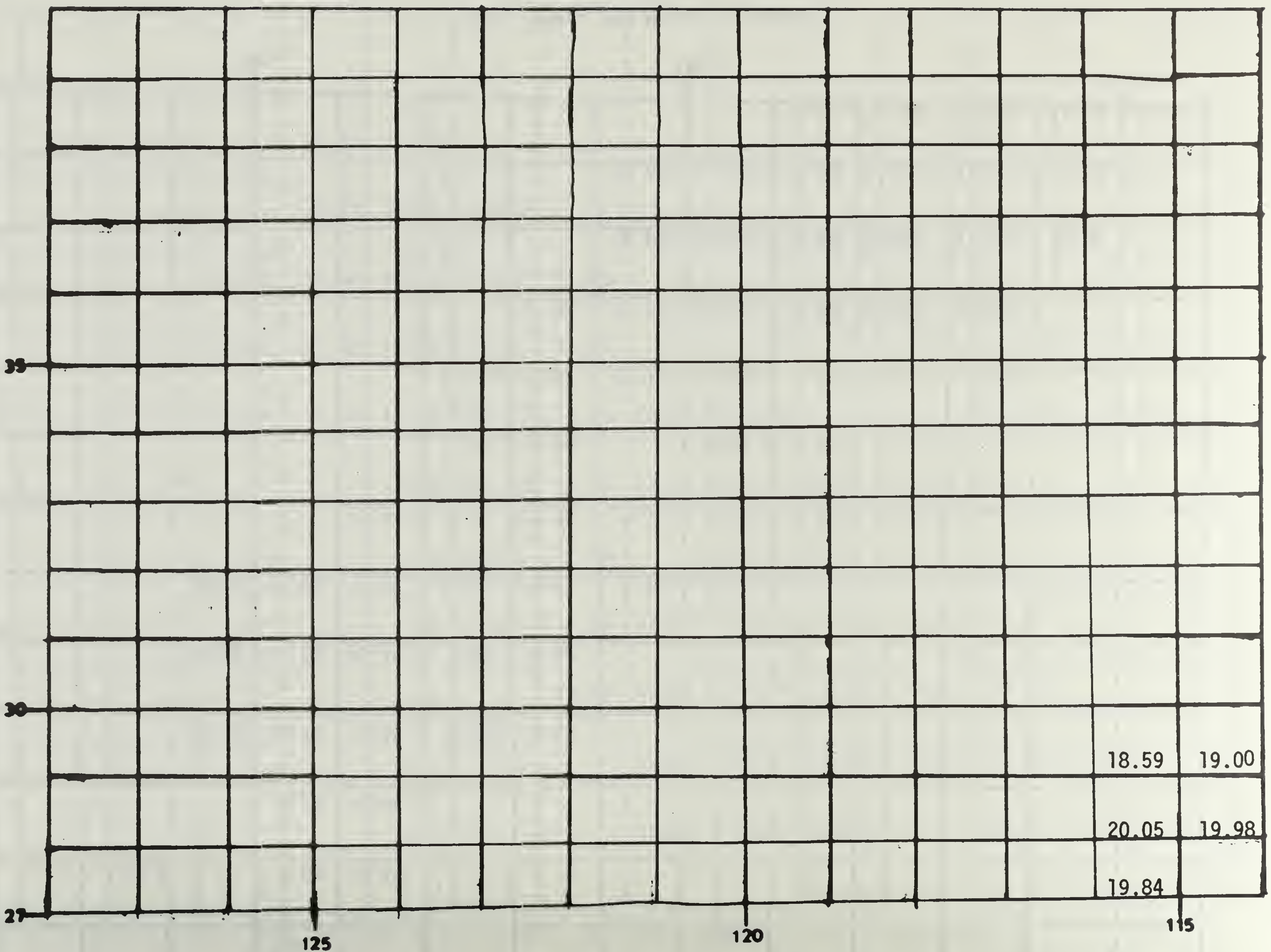
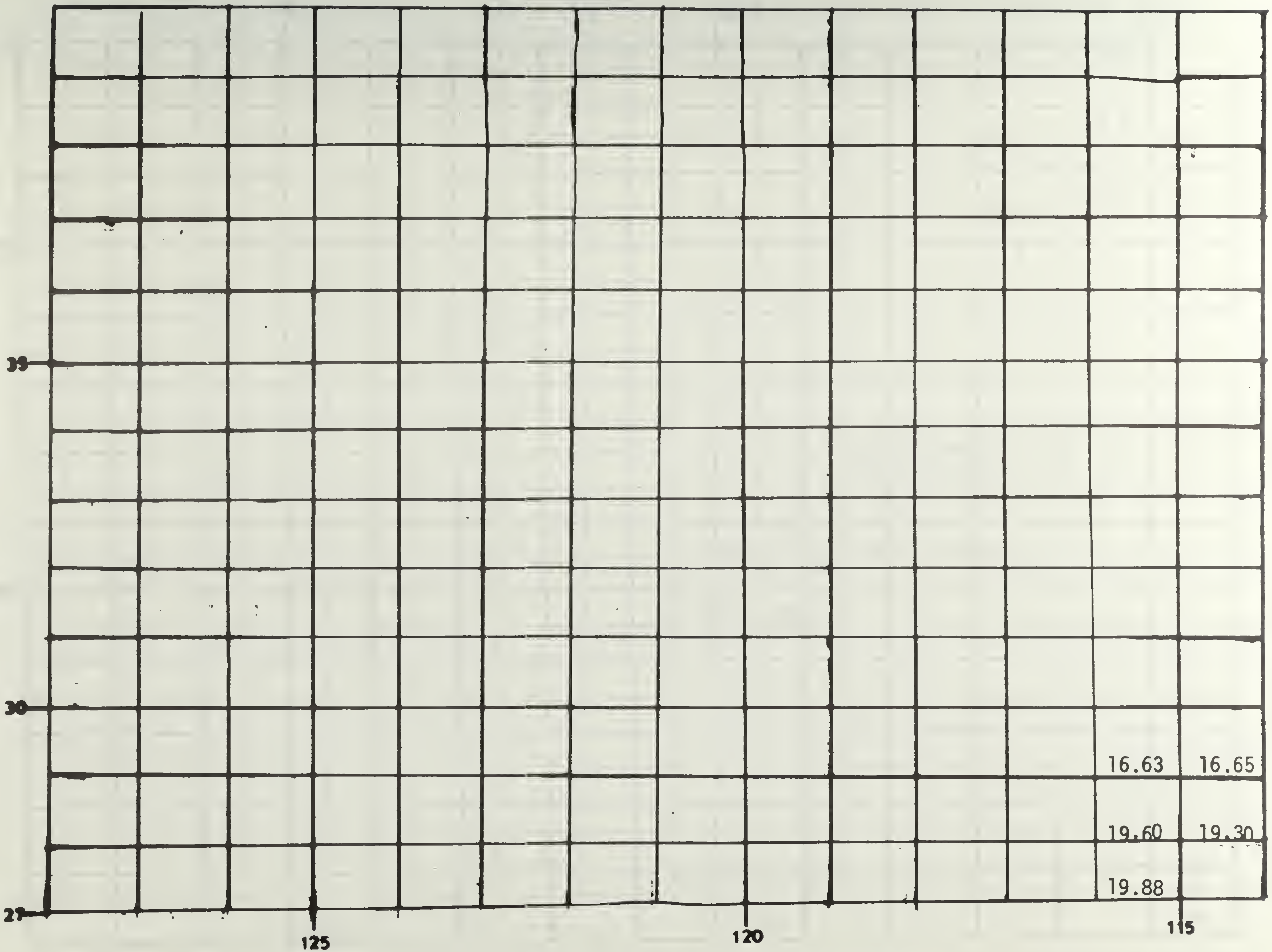
July 1958 - 10 Meter Isotherms



July 1958 - 100 Meter Isotherms



August 1958 - Surface Isotherms



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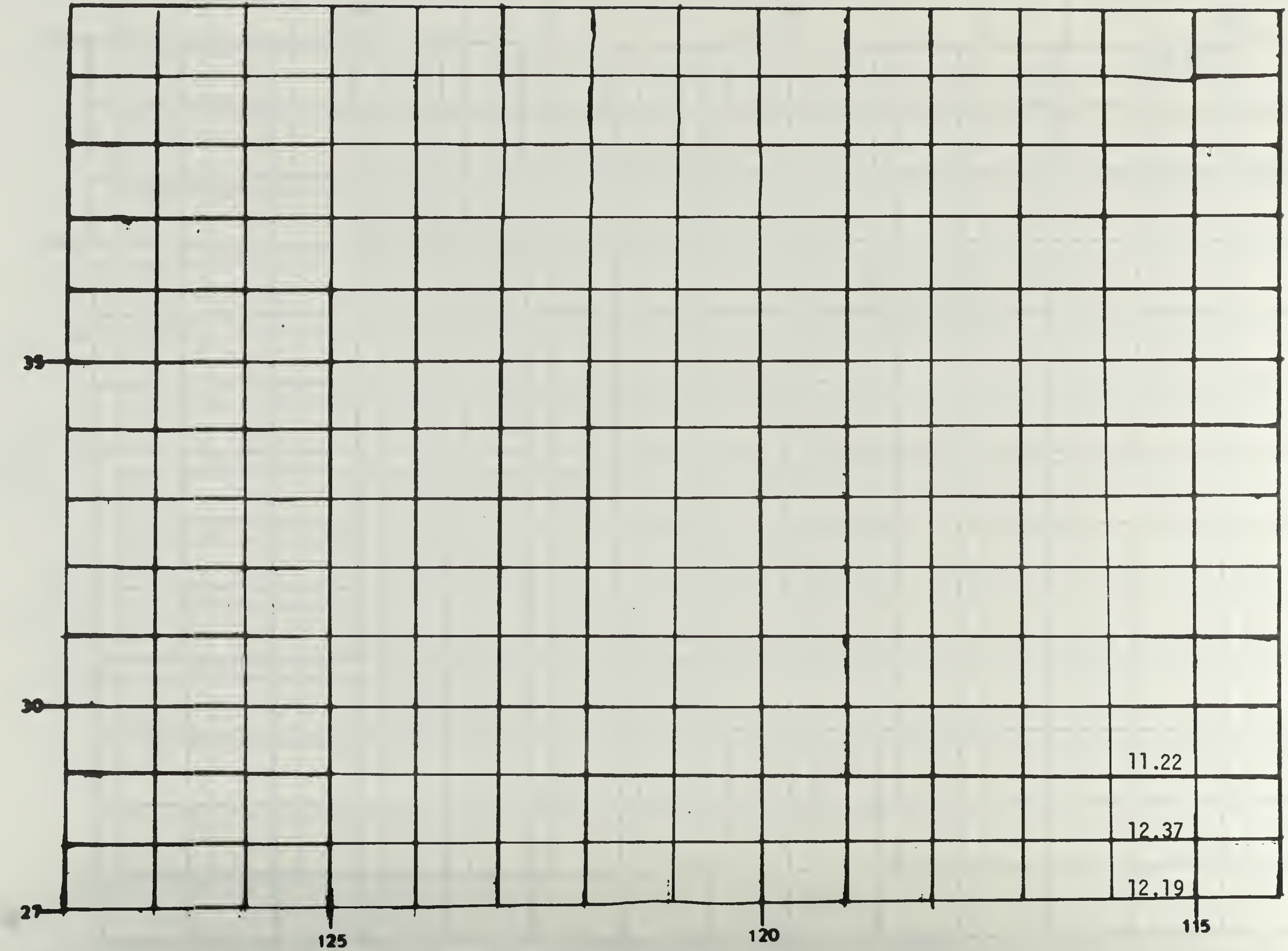

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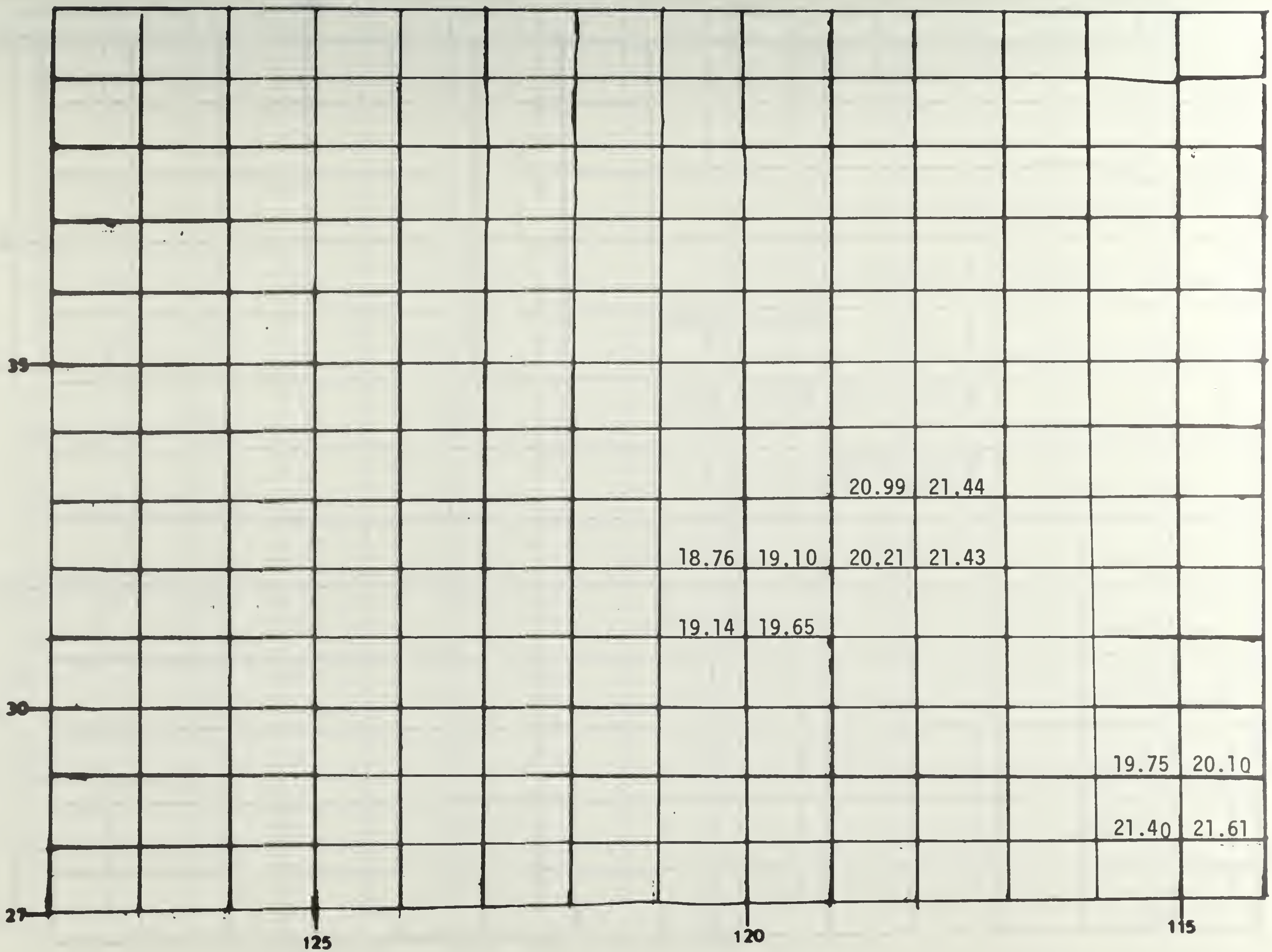
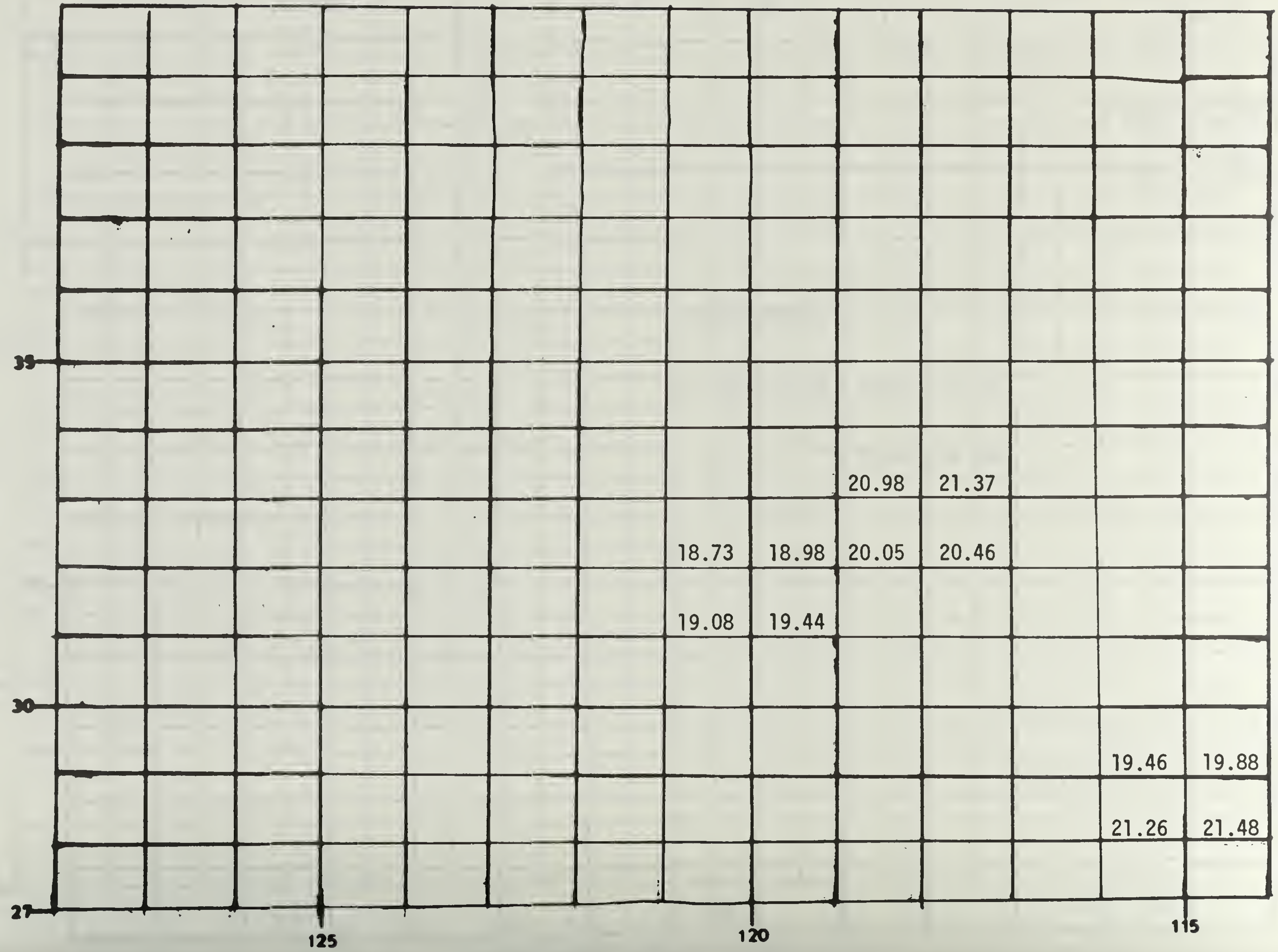


September 1958 - Surface Isotherms



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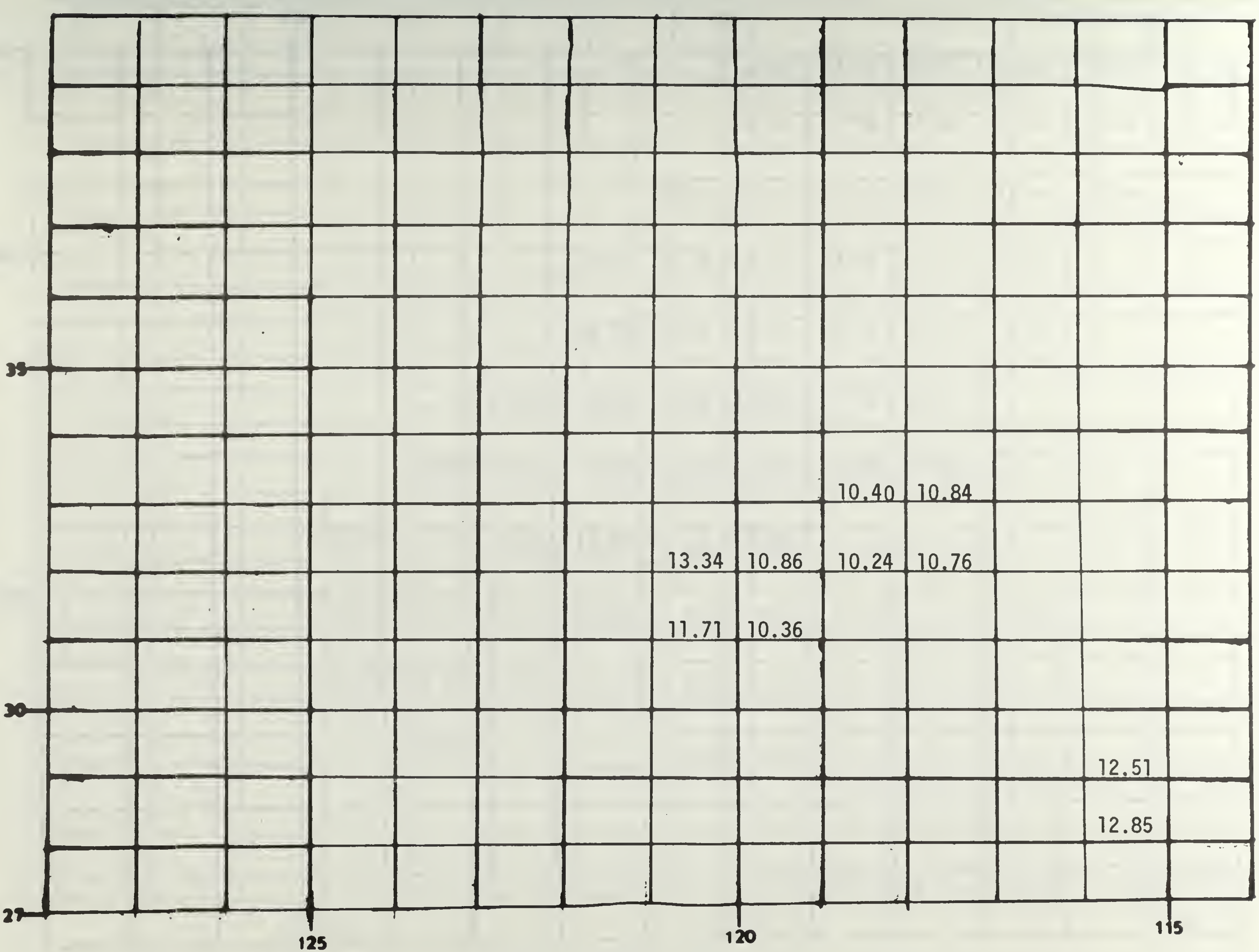


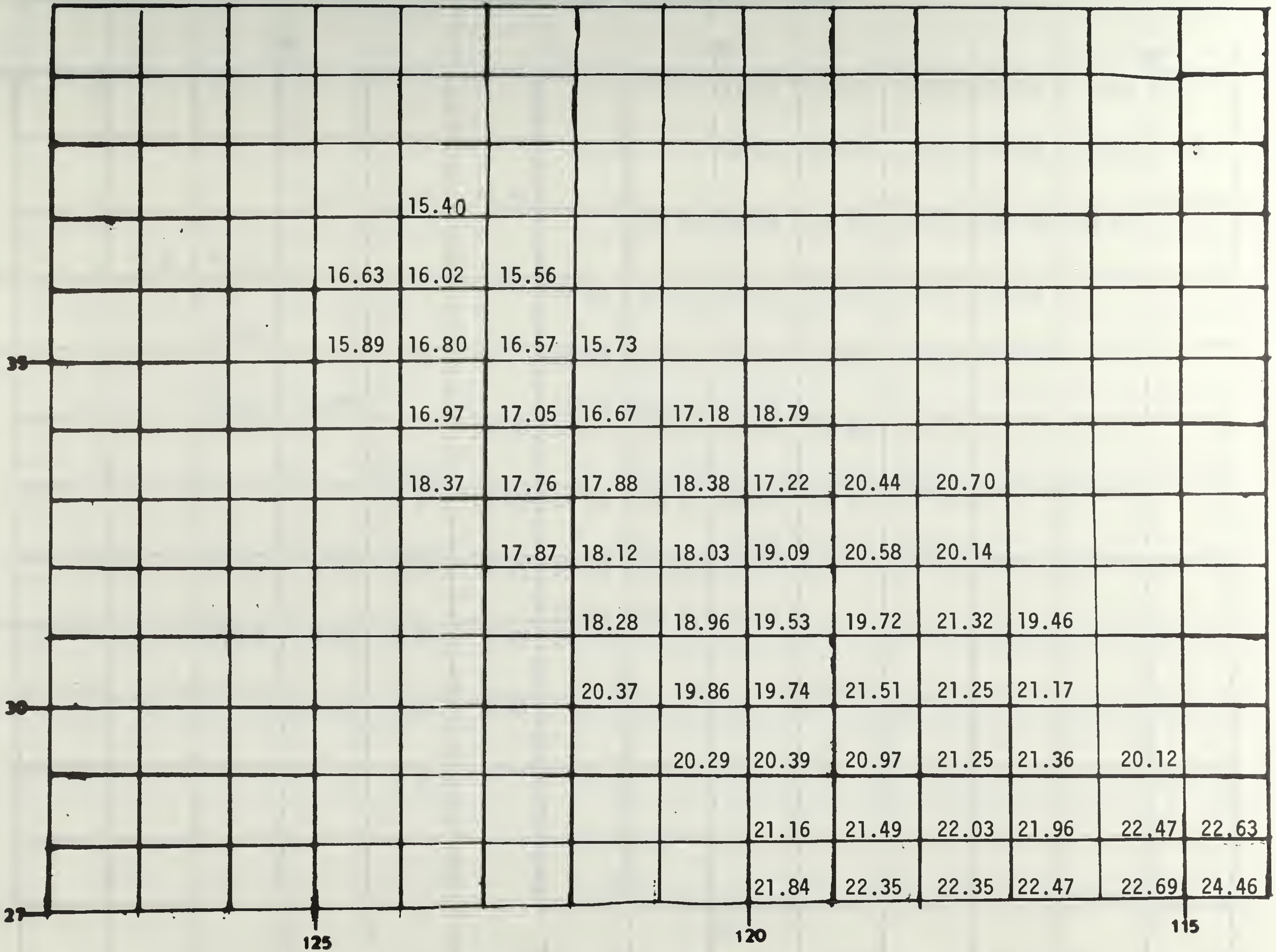
September 1958 - 100 Meter Isotherms

				15.46									
			16.62	16.07	15.57								
			15.87	16.84	16.60	15.84							
			16.58	17.00	17.06	16.68	17.72	18.88					
				18.48	17.75	17.89	18.54	17.40	20.36	20.72			
					17.90	18.11	18.05	19.21	20.62	20.16			
						18.25	18.94	19.51	20.08	21.38	19.80		
						20.36	19.88	19.74	21.66	21.38	21.67		
							20.34	20.40	21.40	21.25	21.44	20.24	
								21.16	21.80	22.04	21.97	22.57	22.74
								21.84	22.51	22.52	21.96	22.68	24.82

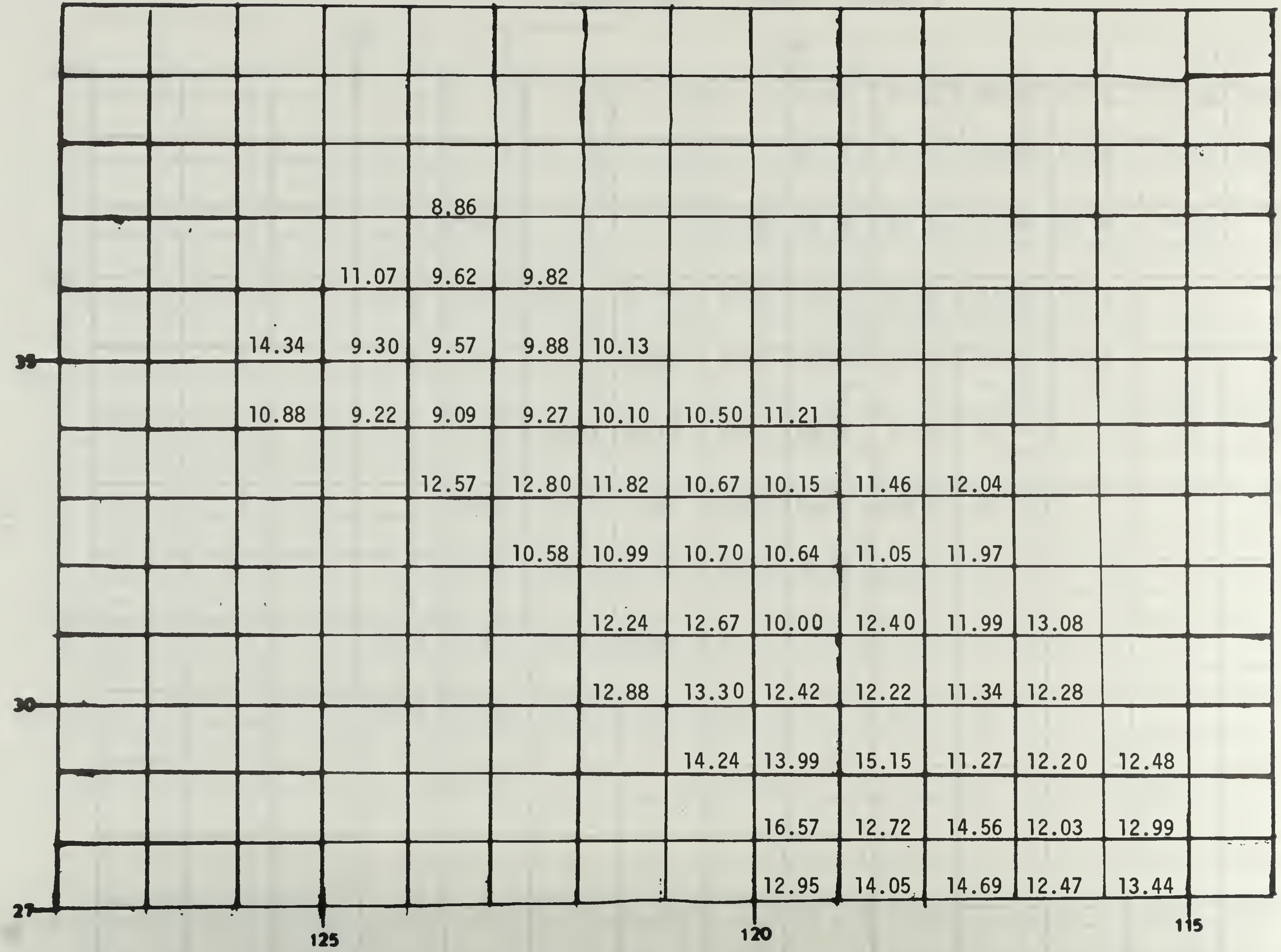
35 30 27

125 120 115

October 1958 - Surface Isotherms



October 1958 - 10 Meter Isotherms



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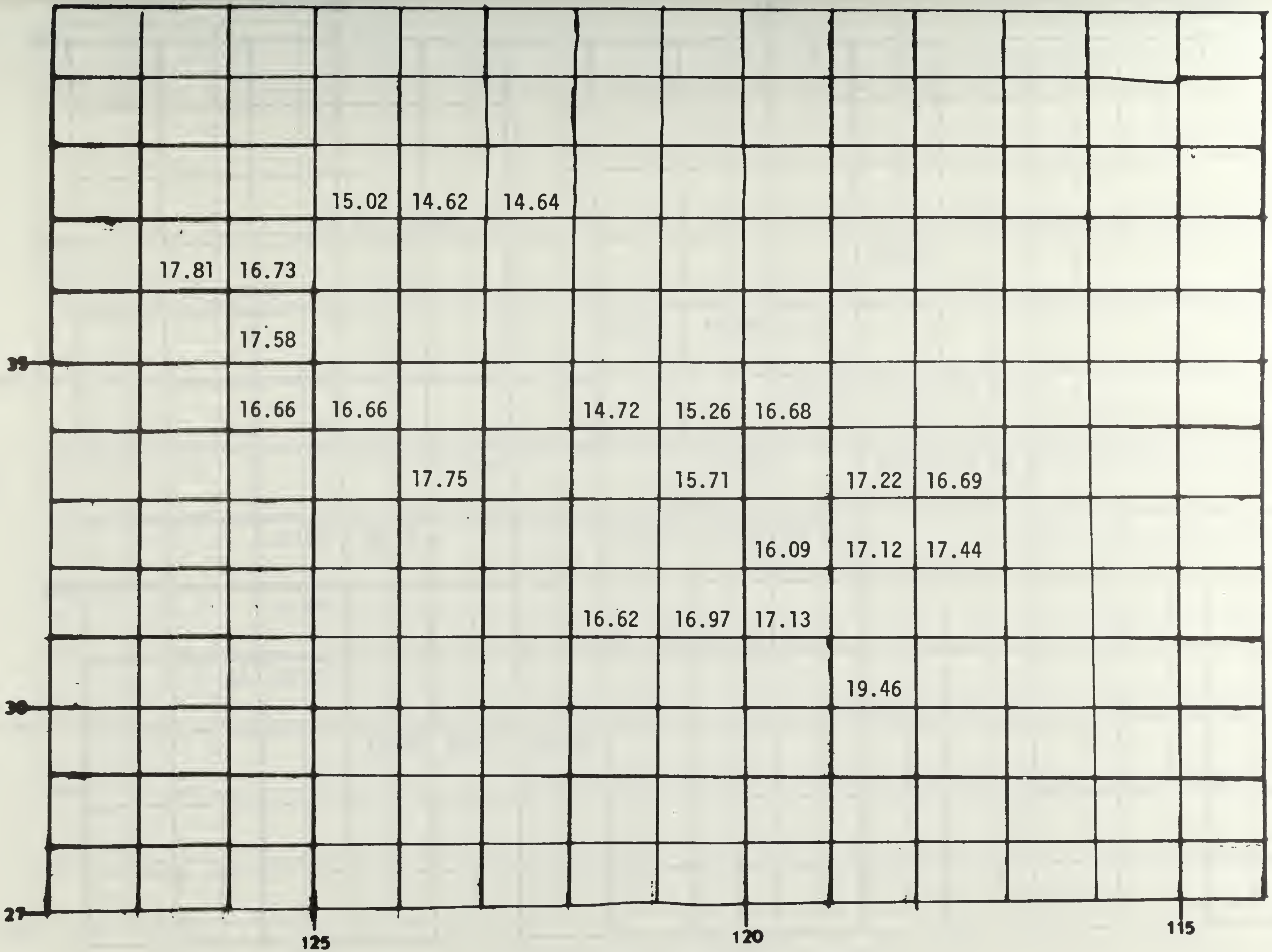
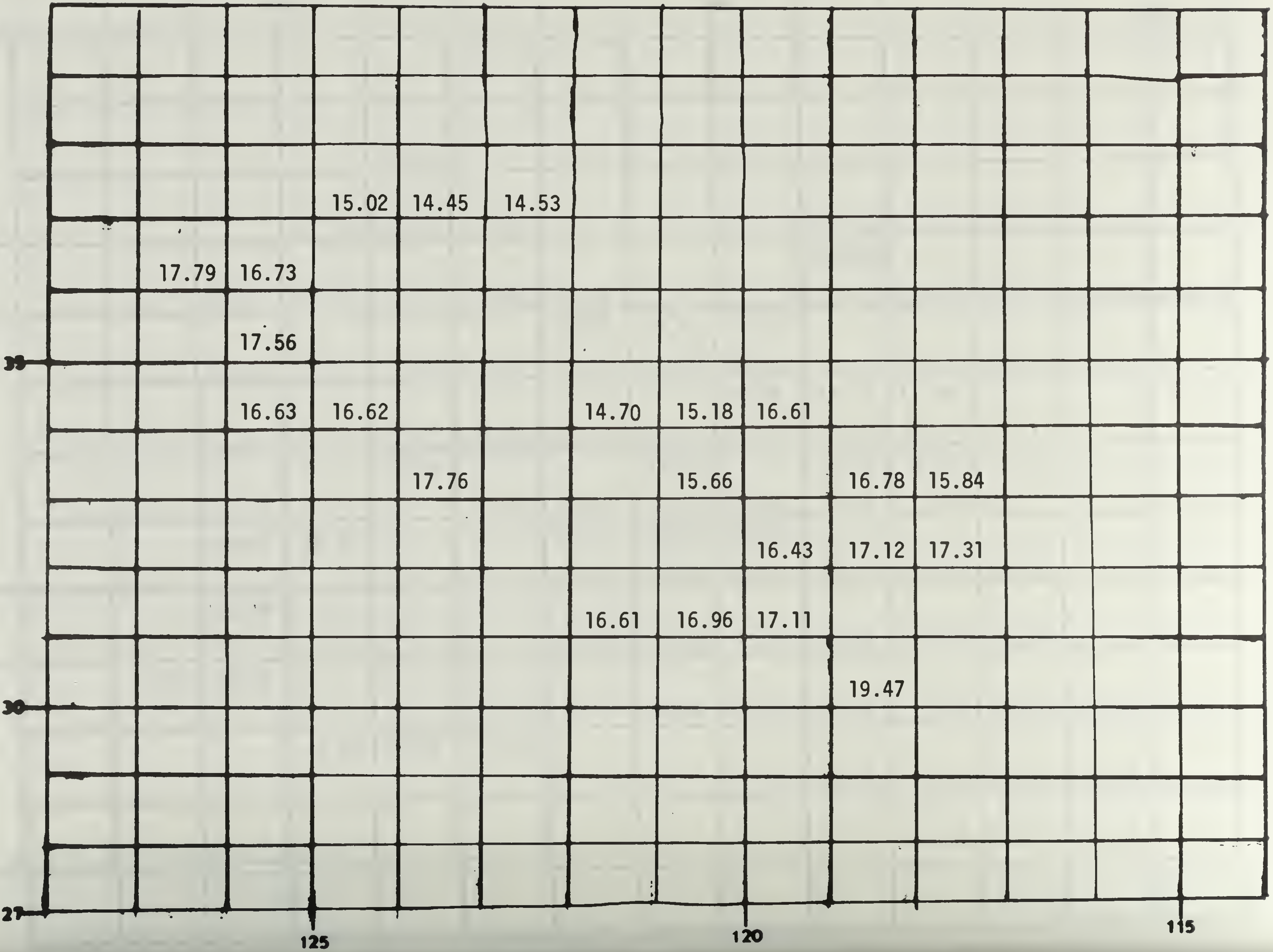


November 1958 - Surface Isotherms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14.53
17.79
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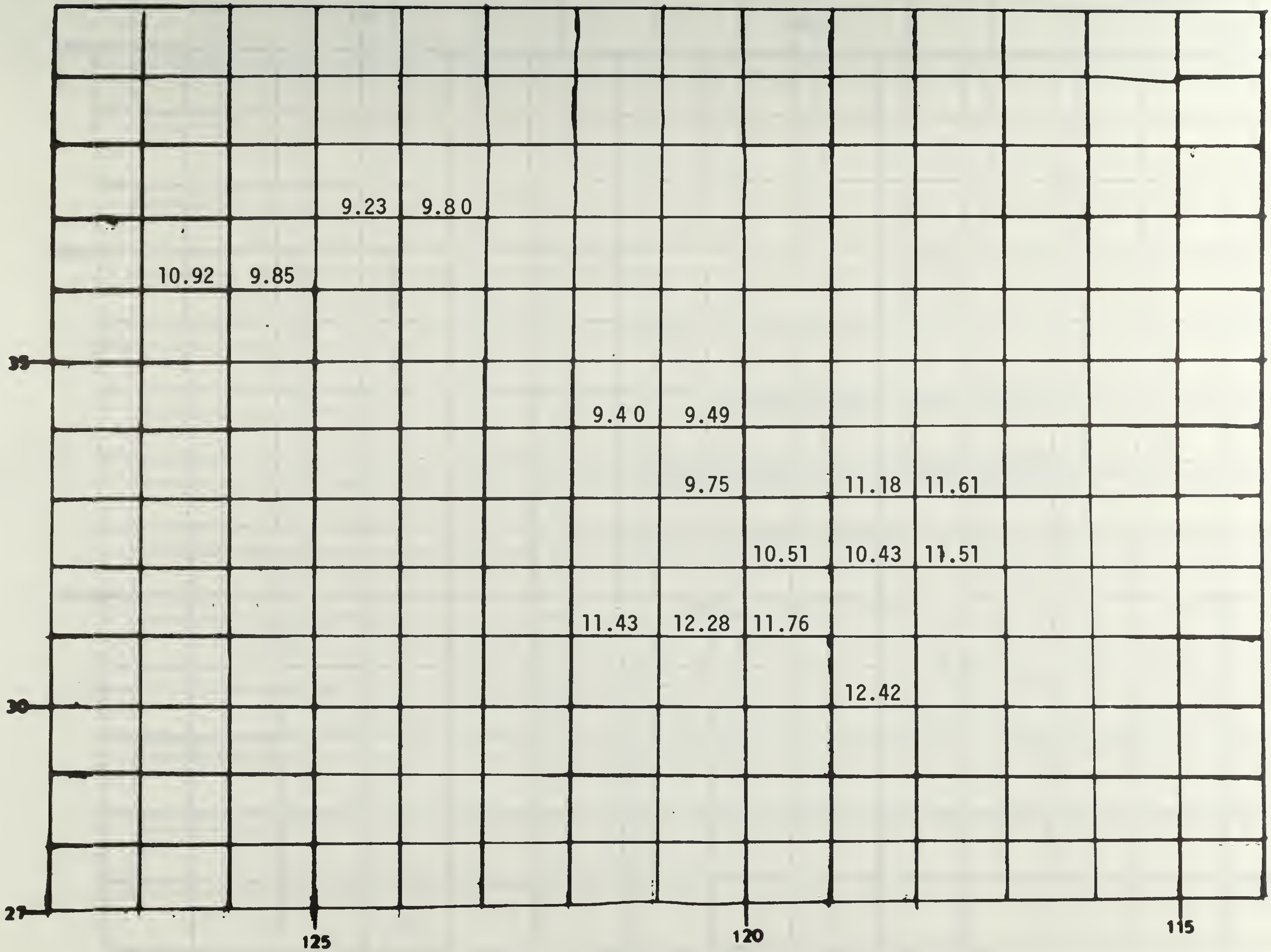
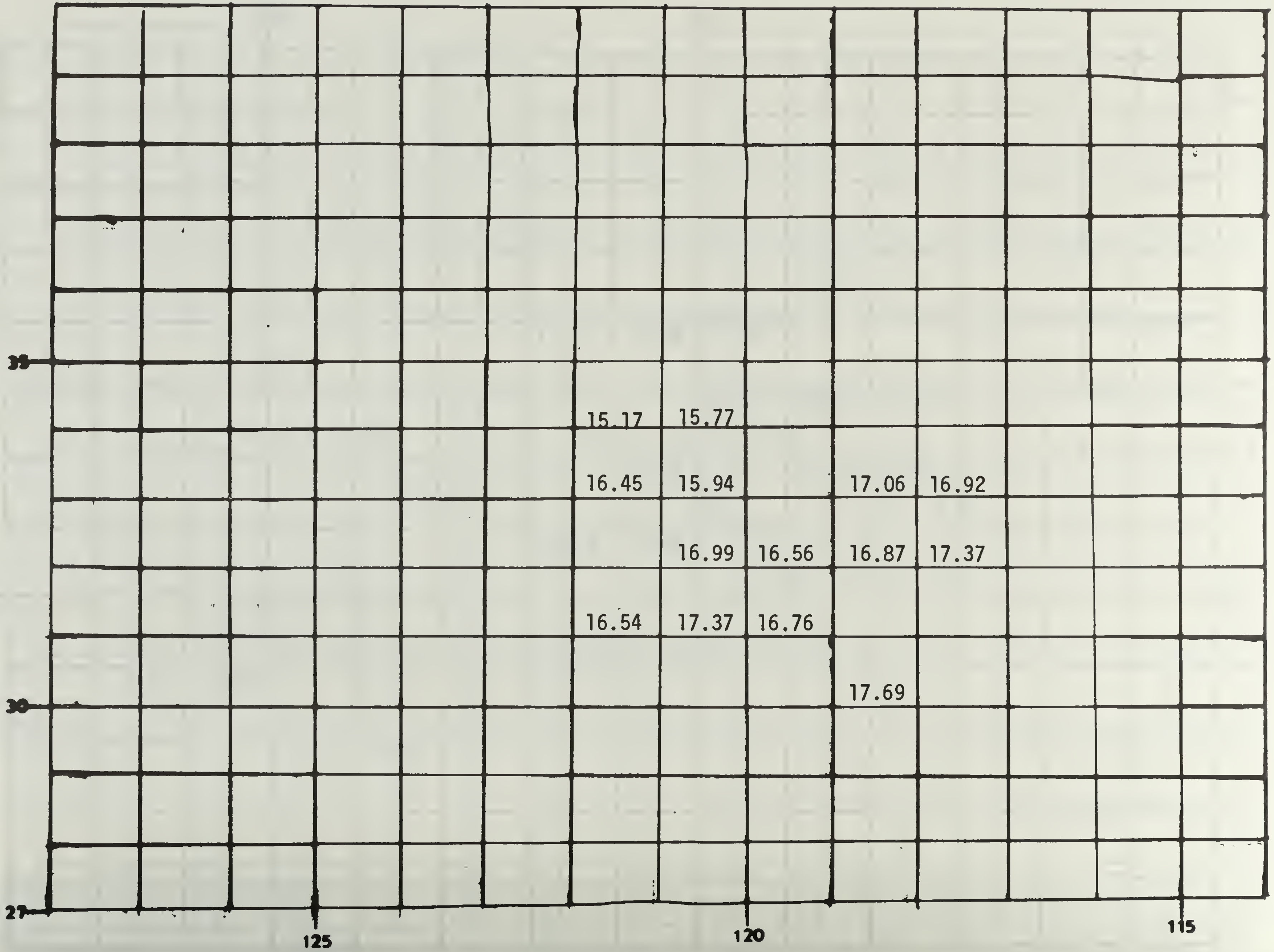
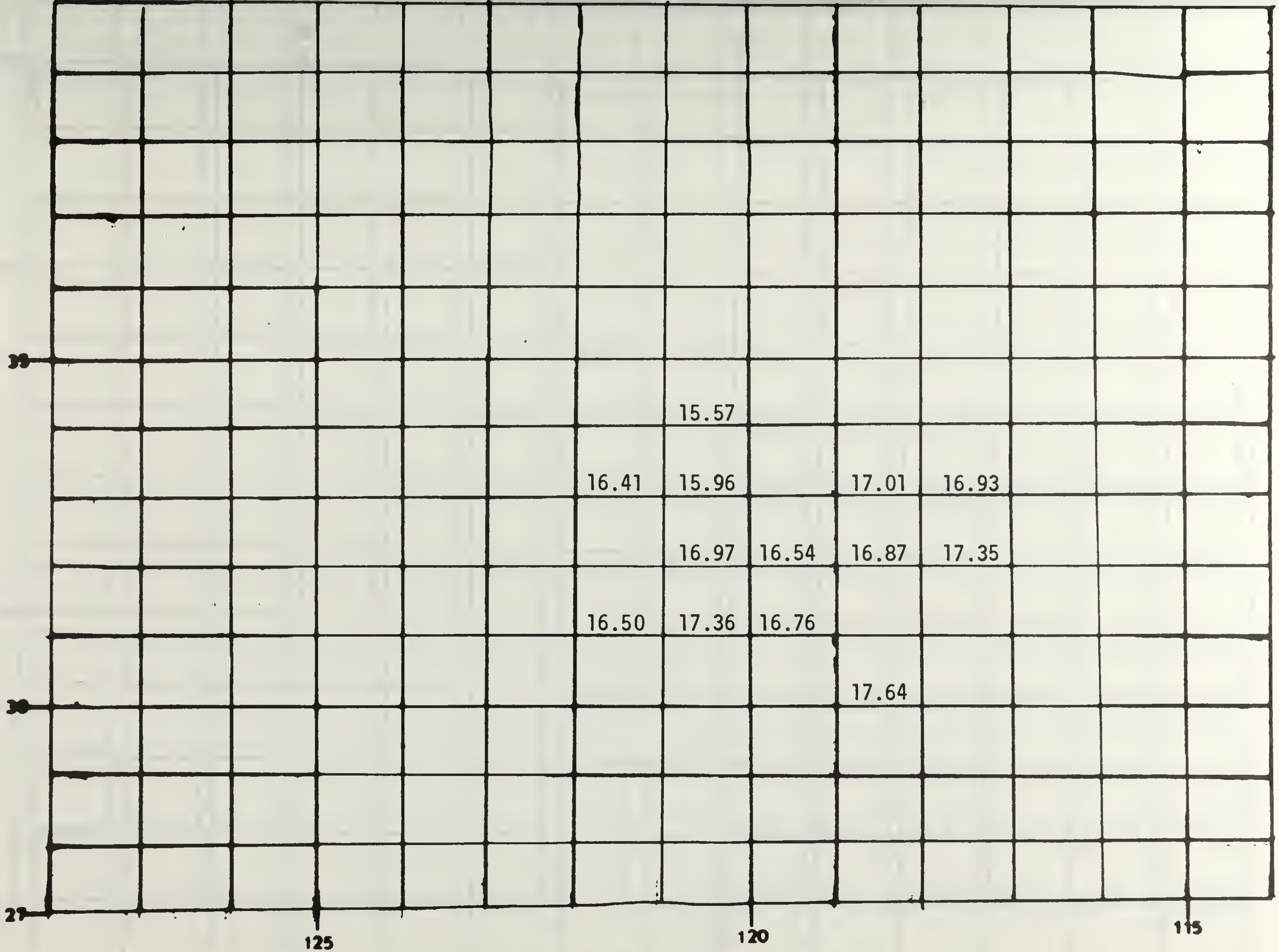
17.56
16.63
16.62
14.70
15.18
16.61
17.76
15.66
16.78
15.84
16.43
17.12
17.31
16.61
16.96
17.11
19.47
33
30
27
125
120
115



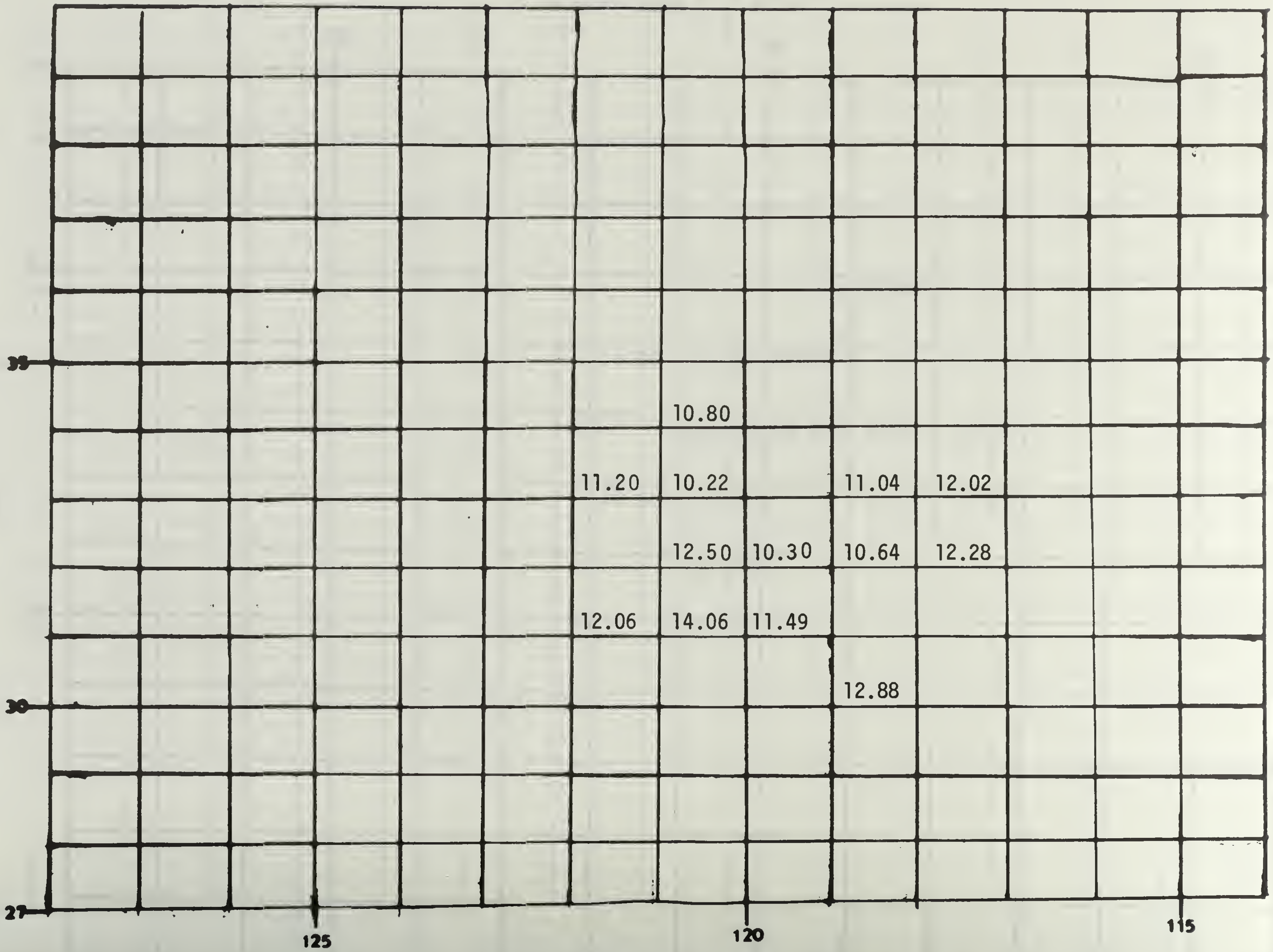
November 1958 - 100 Meter Isotherms



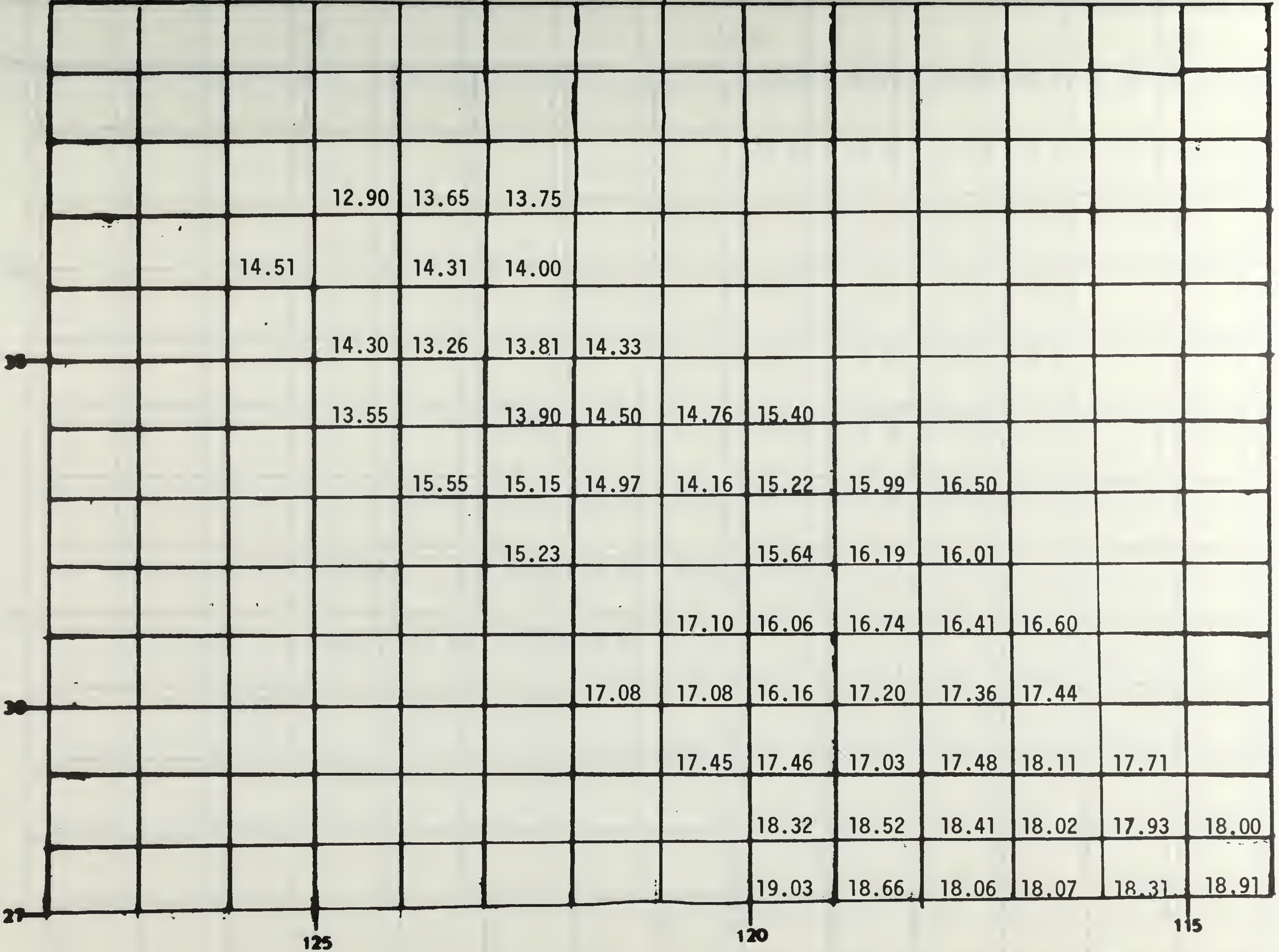
December 1958 - Surface Isotherms



December 1958 - 10 Meter Isotherms



December 1958 - 100 Meter Isotherms



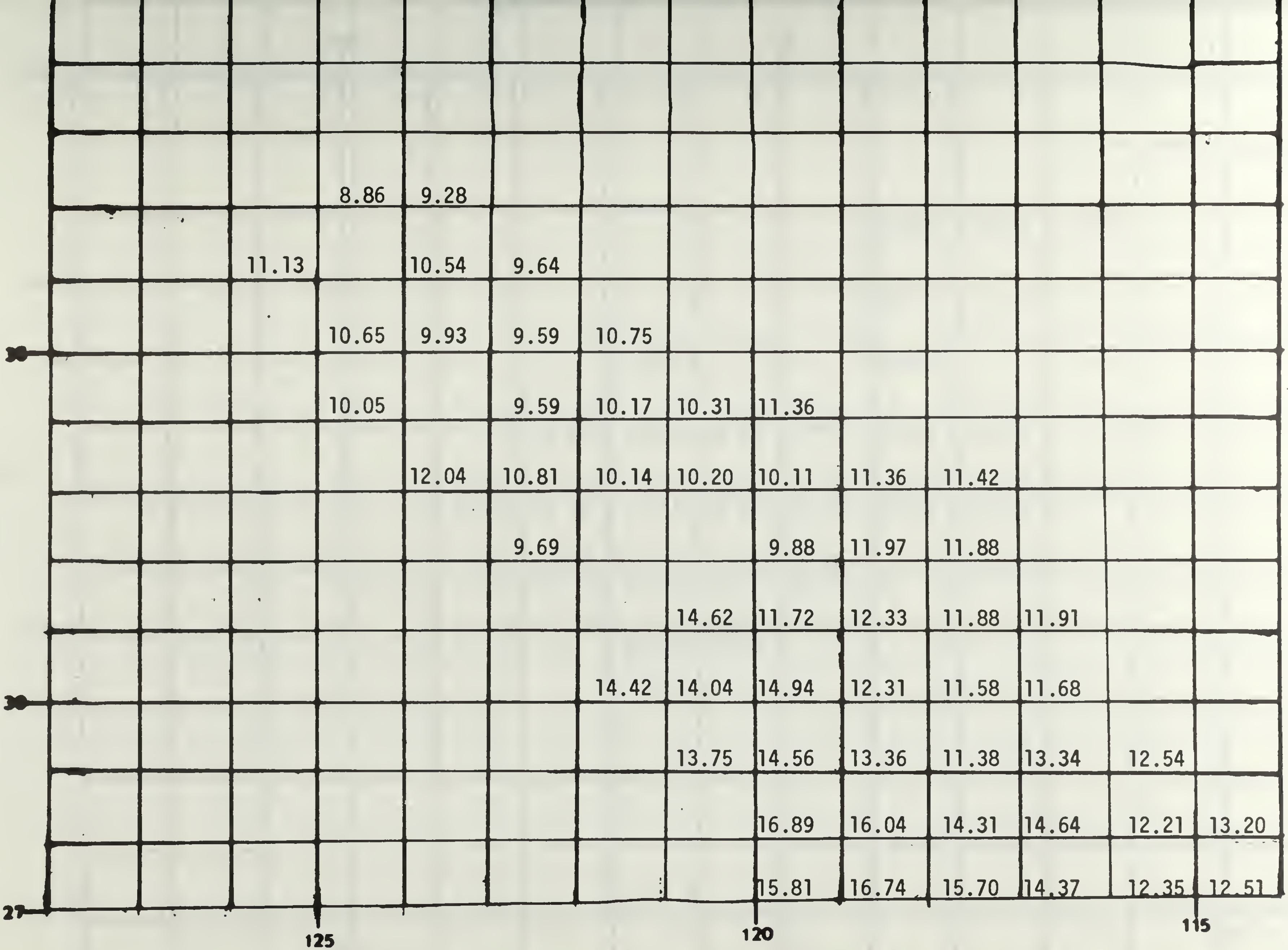
January 1959 - Surface Isotherms

			12.90	13.64	13.75								
		14.50		14.30	13.99								
			14.32	13.26	13.60	14.33							
			13.55		13.90	14.54	14.61	15.38					
				15.55	15.14	14.97	14.63	15.23	15.83	15.84			
					15.21			15.64	16.19	16.00			
							17.09	16.37	16.73	16.41	16.54		
						17.09	17.10	16.61	17.17	17.35	17.40		
							17.47	17.41	12.03	17.48	17.96	17.53	
								18.21	18.54	18.34	18.03	17.61	17.94
								19.03	18.63	18.04	18.04	18.31	19.19

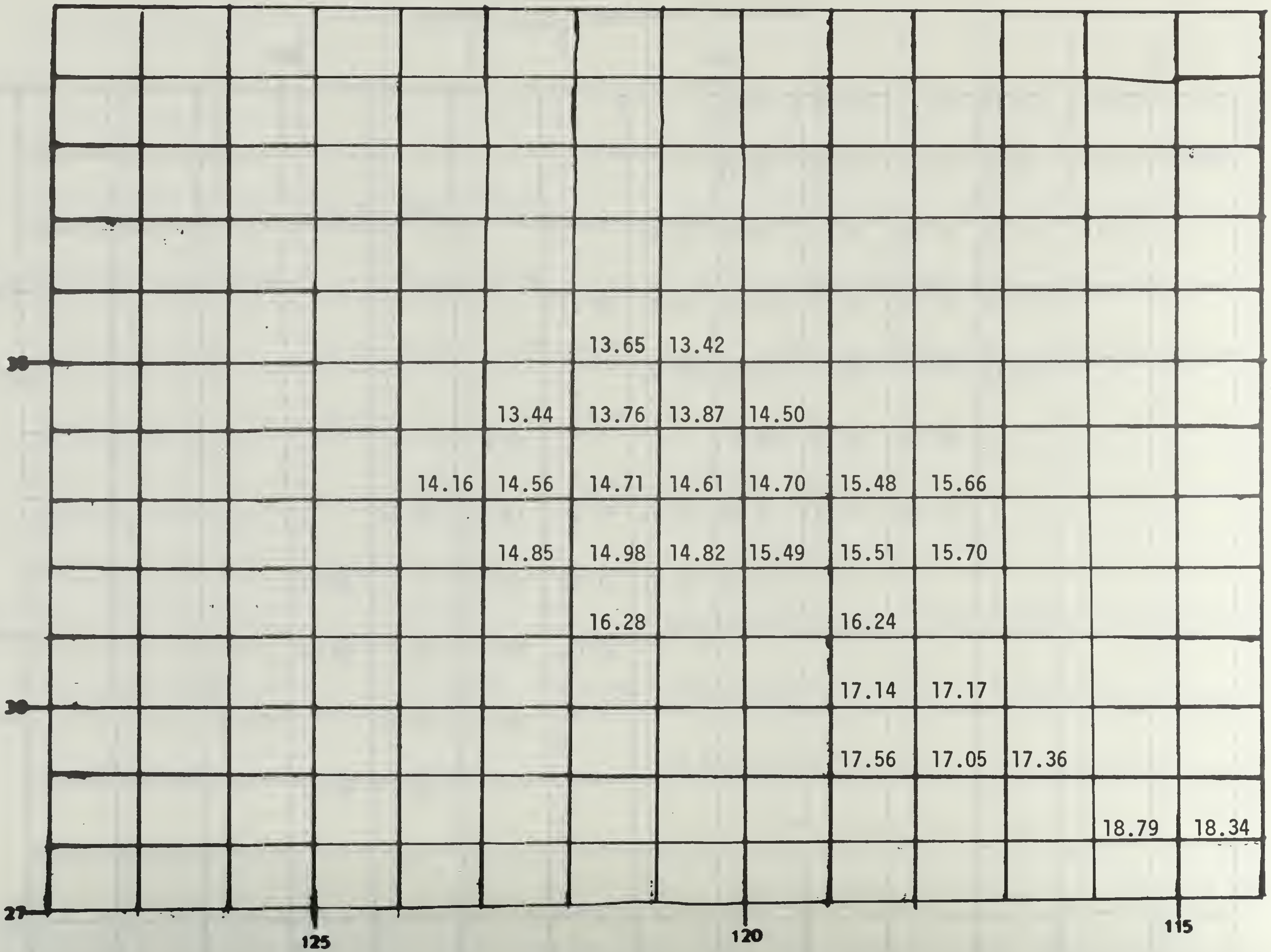
35 30 27

125 120 115

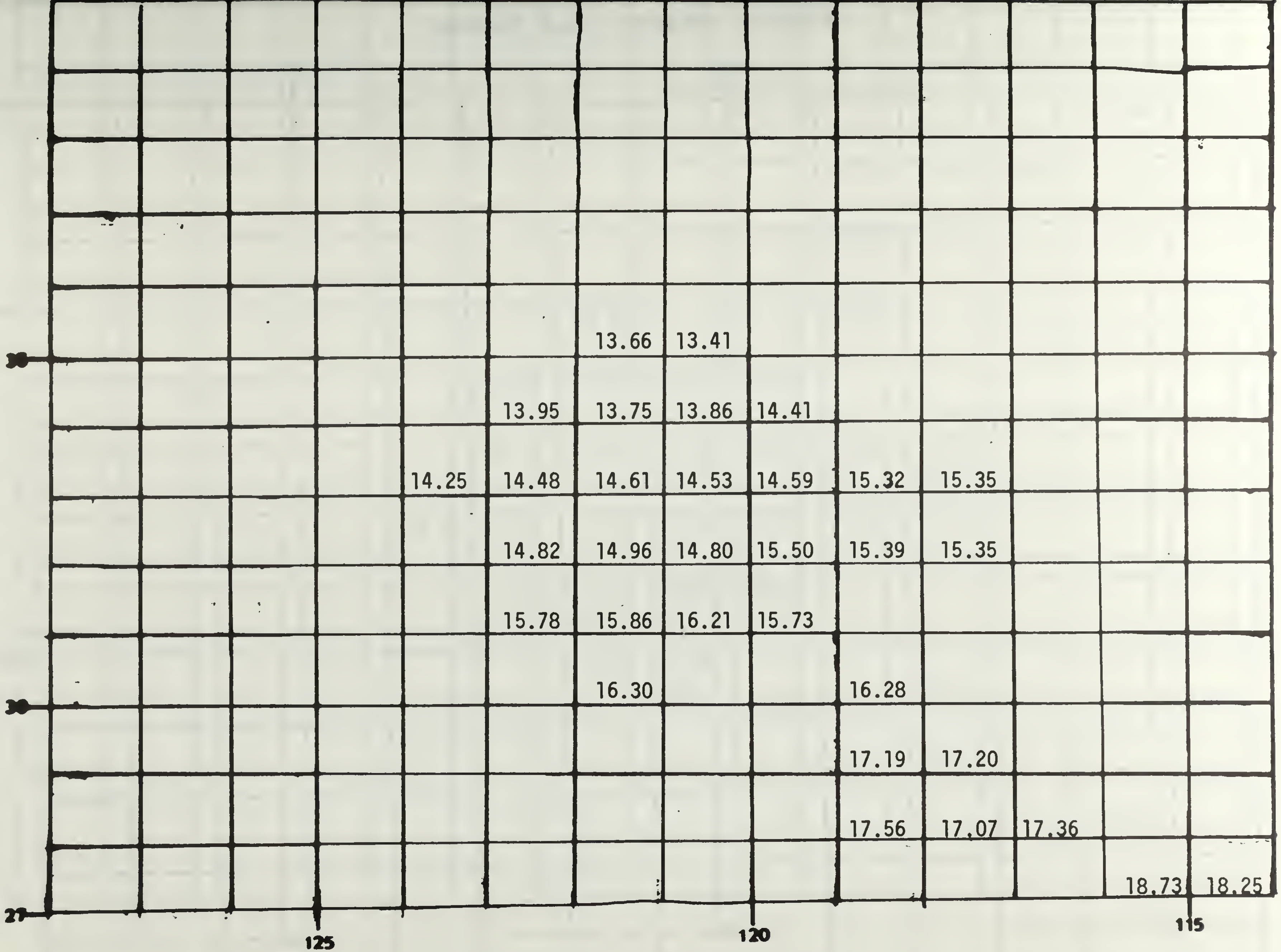
January 1959 - 10 Meter Isotherms



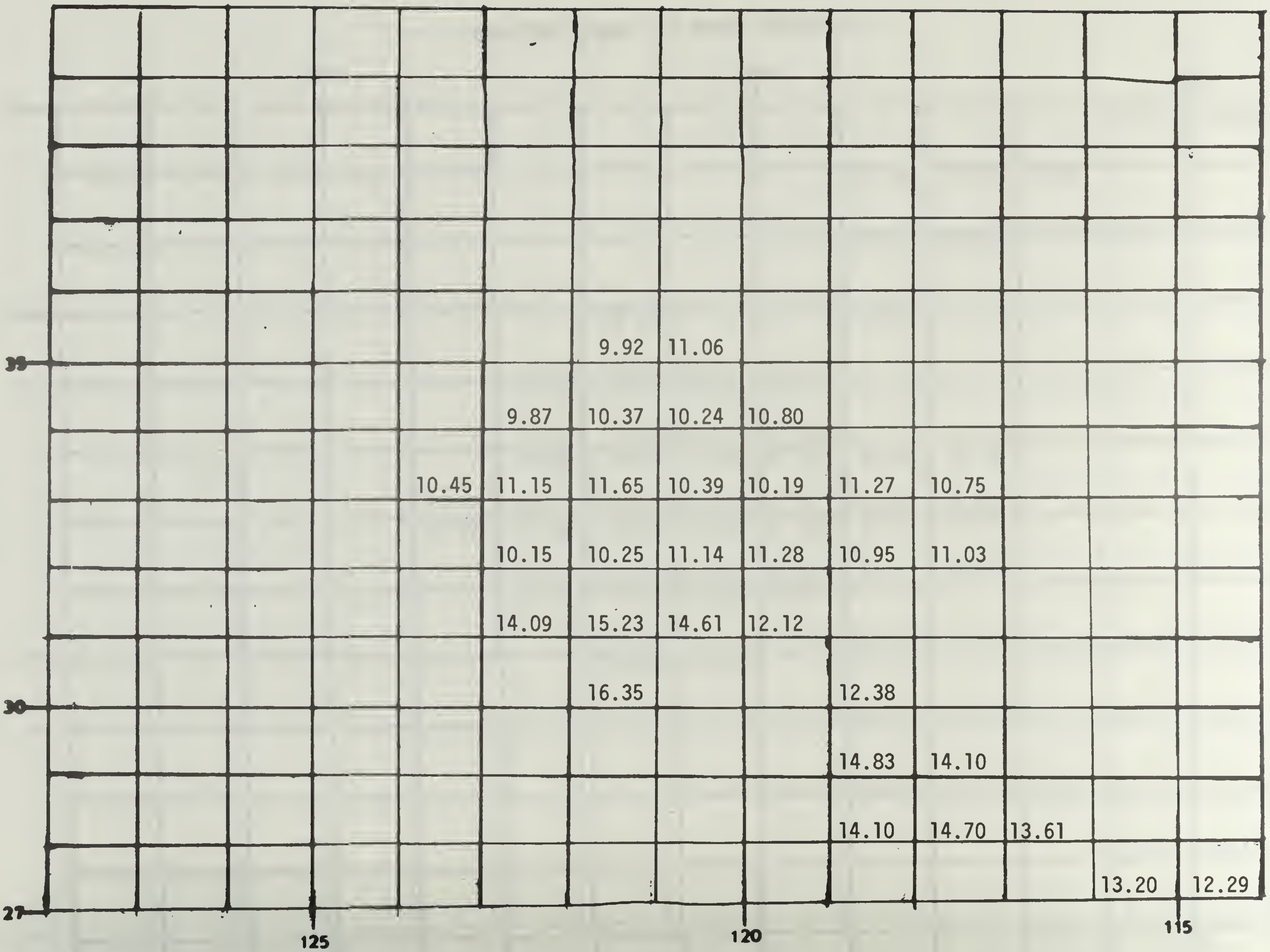
January 1959 - 100 Meter Isotherms



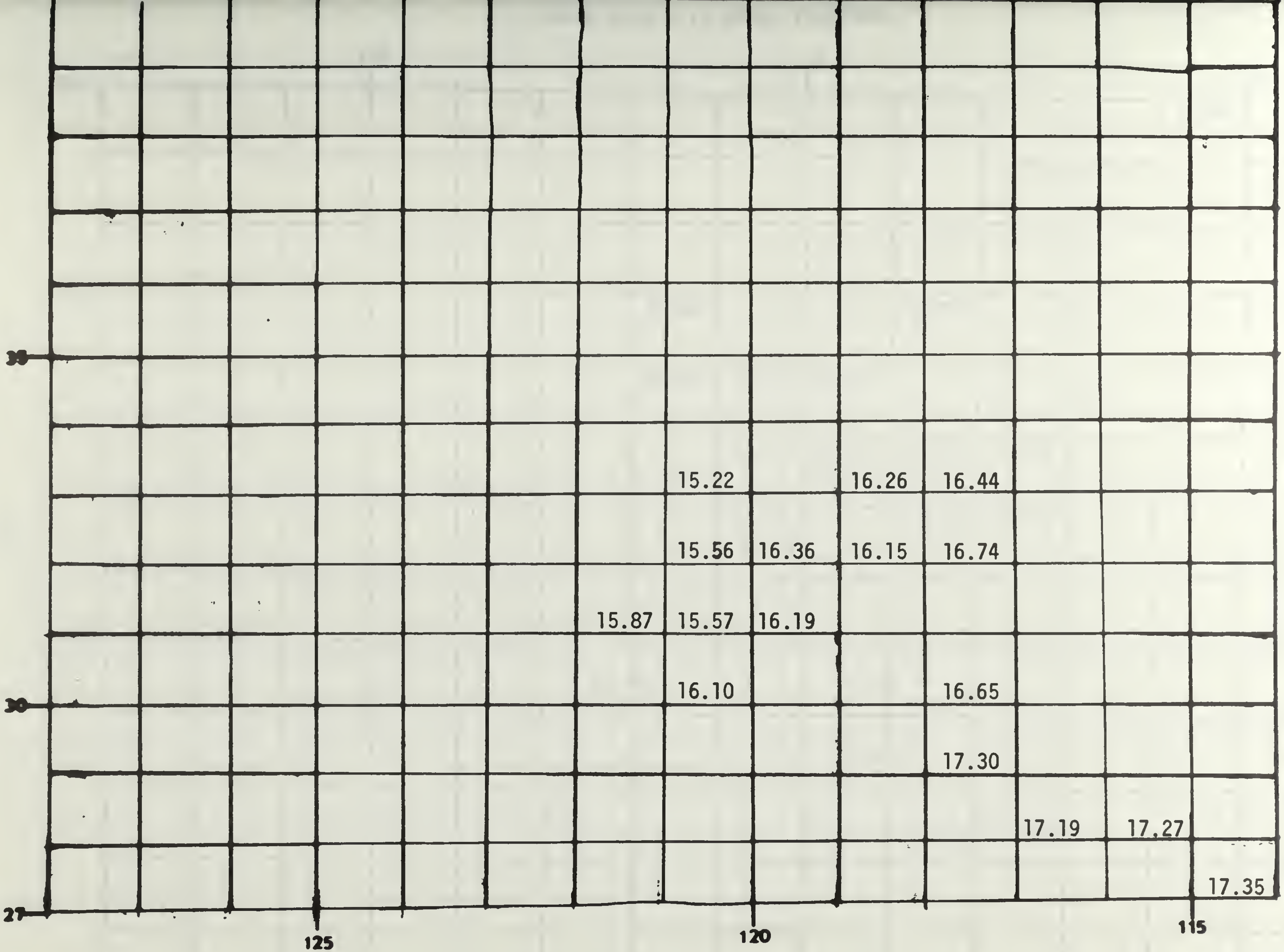
February 1959 - Surface Isotherms



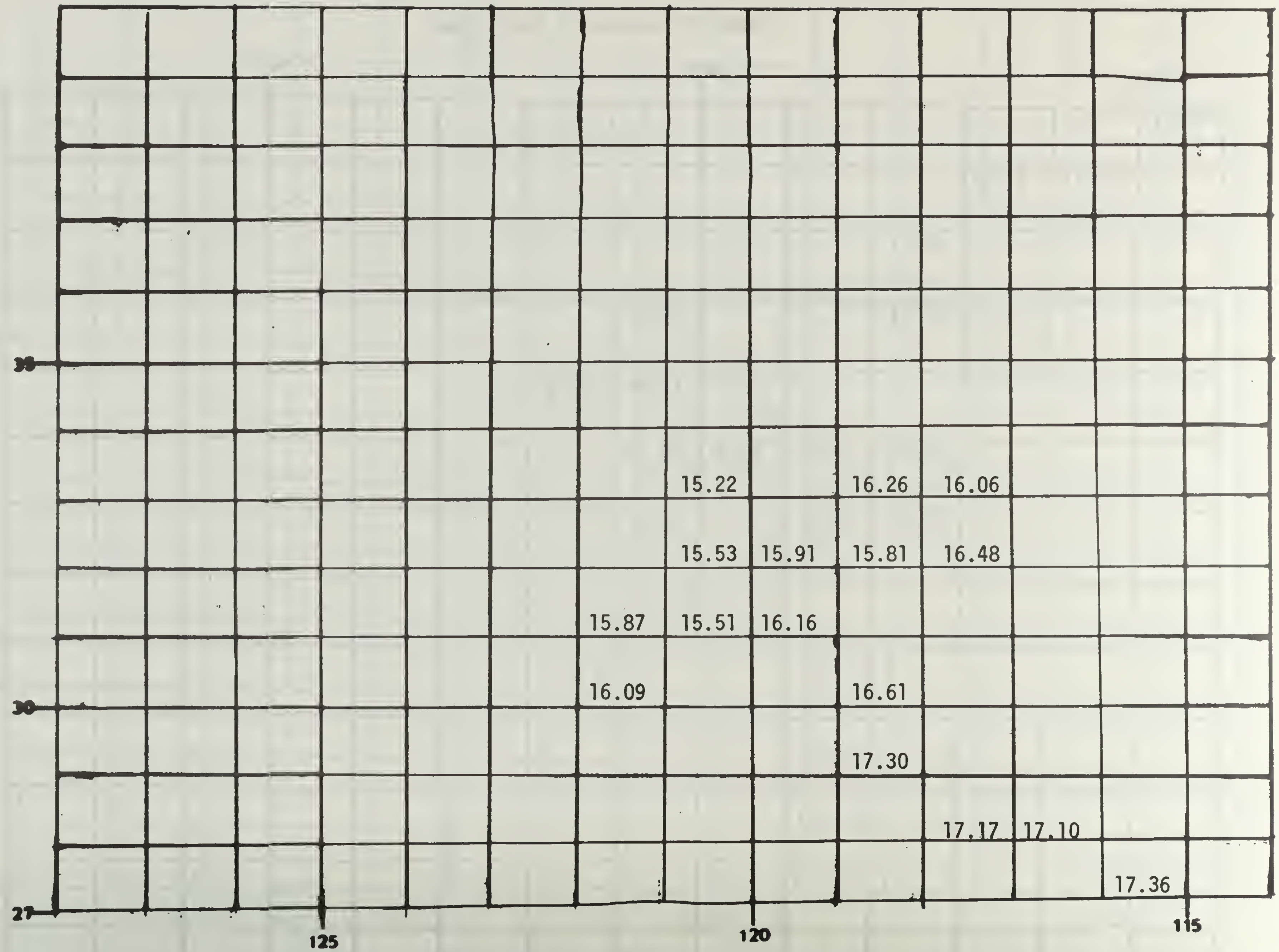
February 1959 - 10 Meter Isotherms



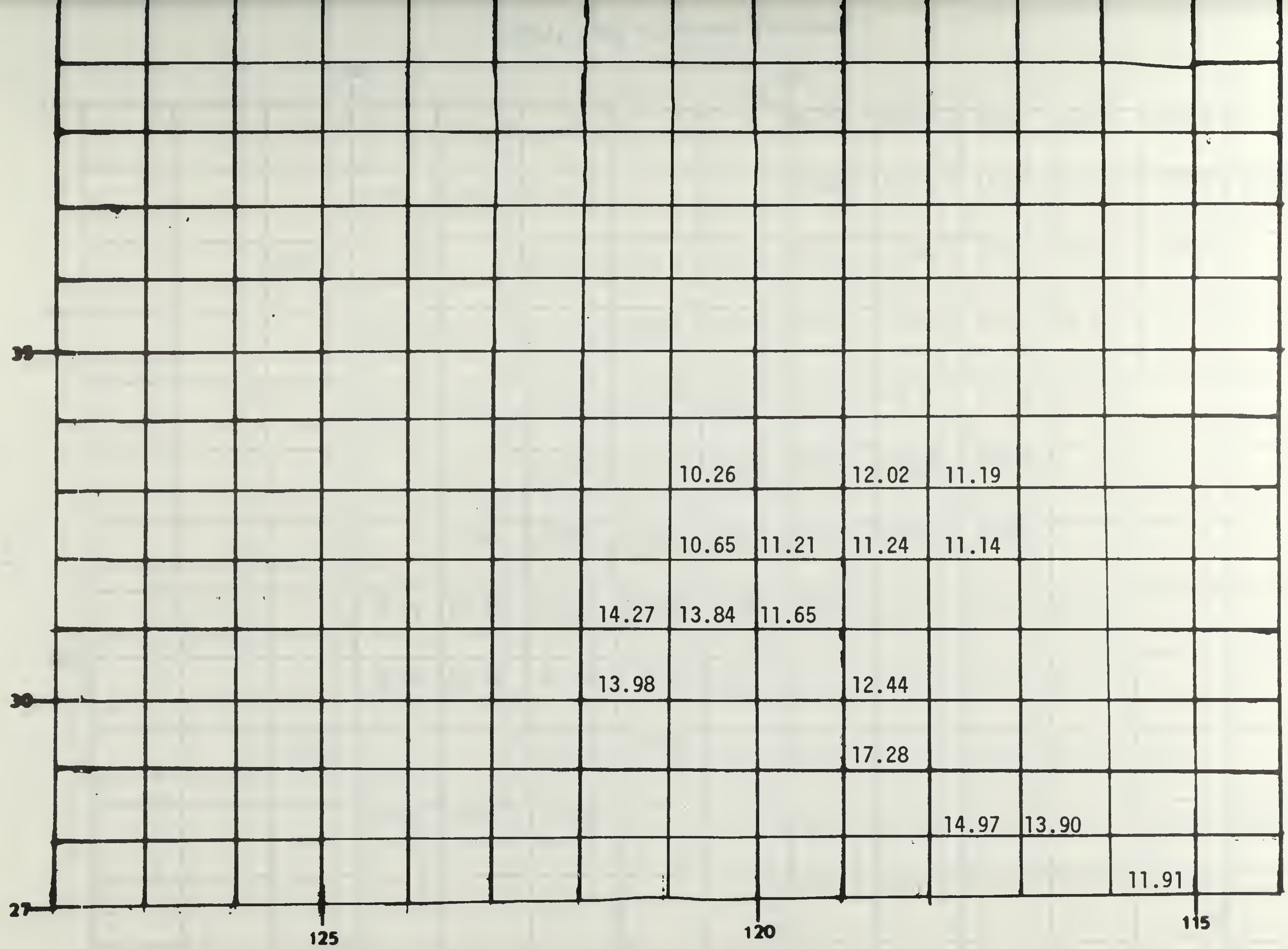
February 1959 - 100 Meter Isotherms



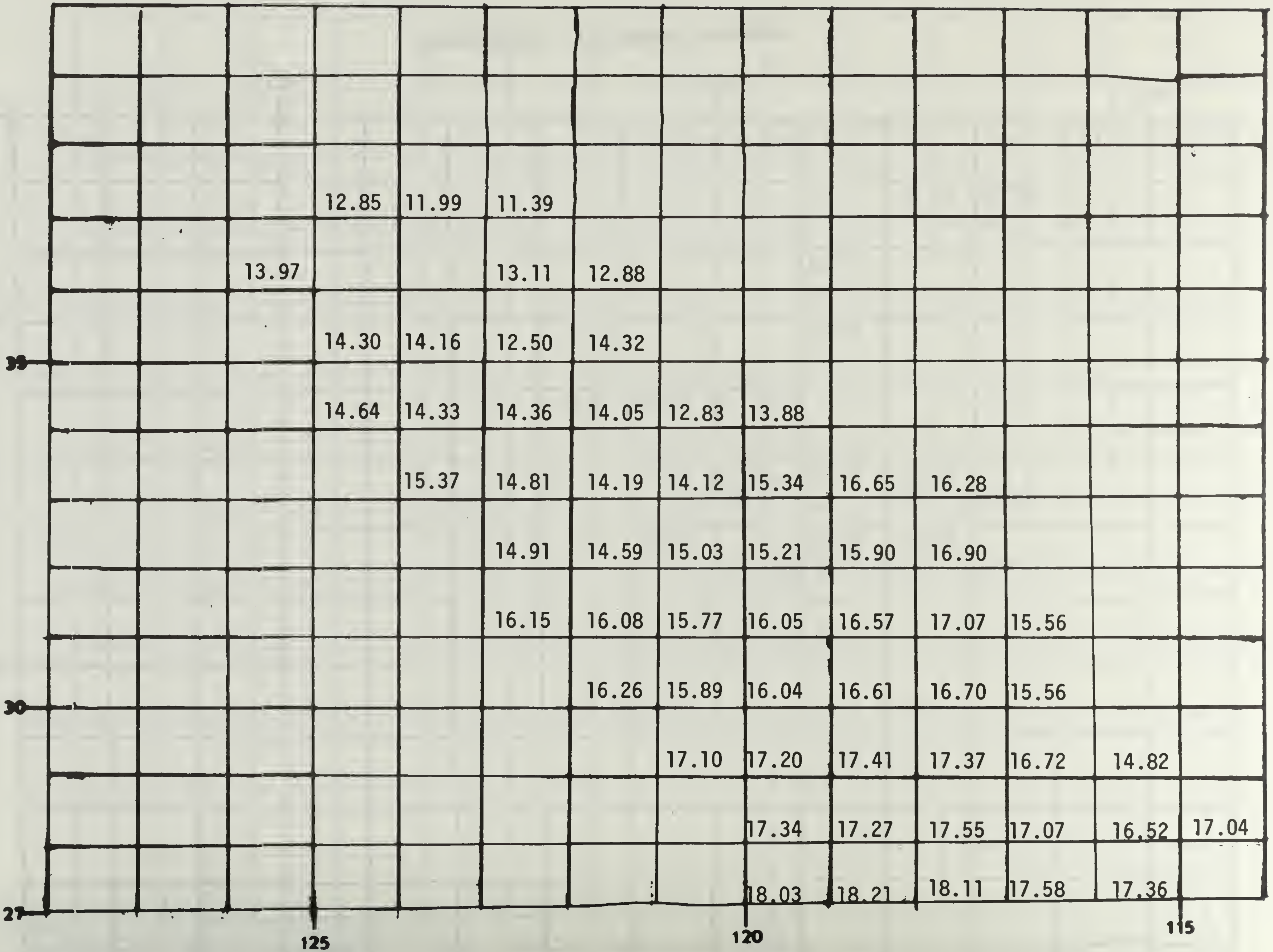
March 1959 - Surface Isotherms



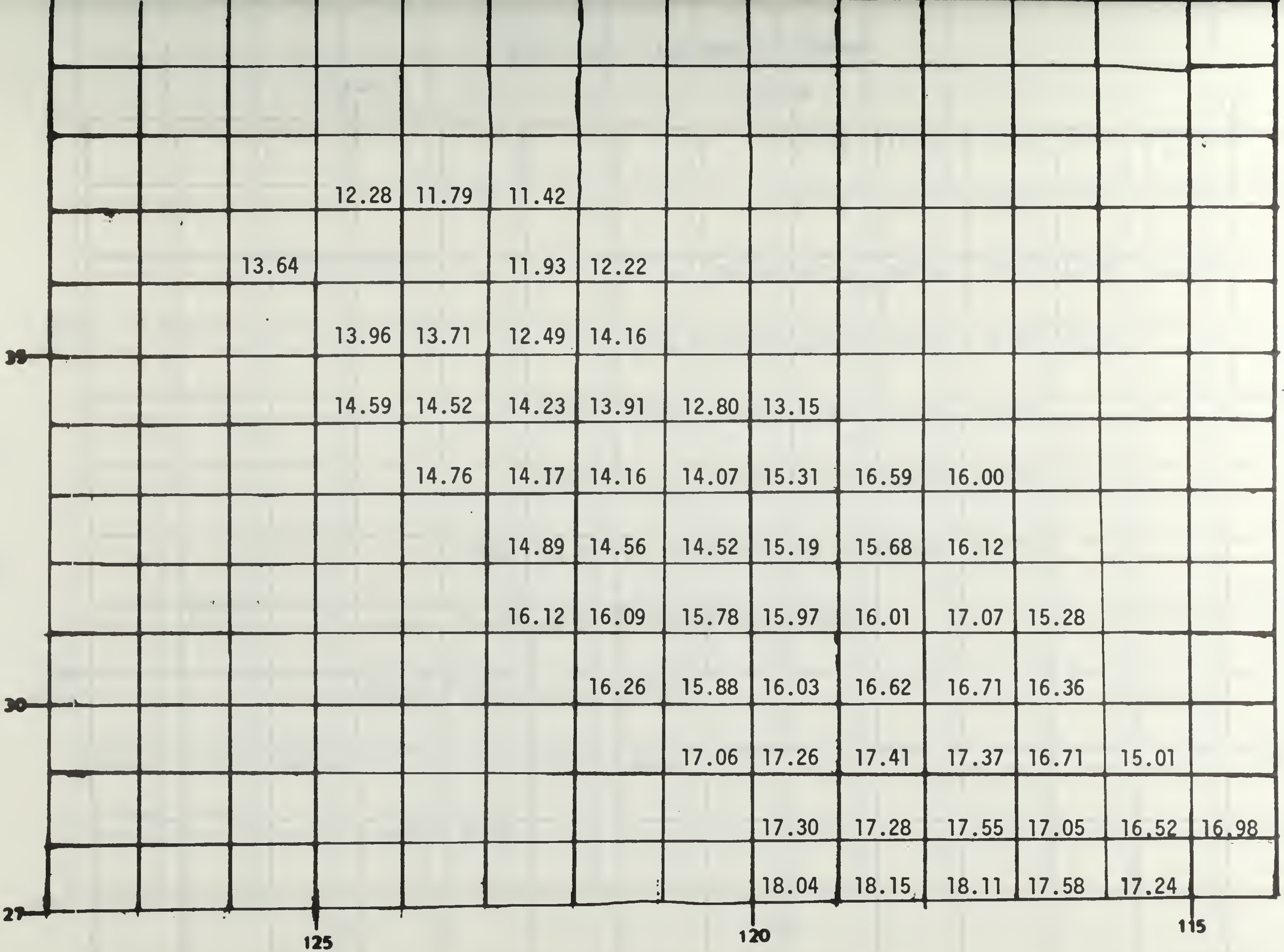
March 1959 - 10 Meter Isotherms



March 1959 - 100 Meter Isotherms



April 1959 - Surface Isotherms



April 1959 - 10 Meter Isotherms

			9.55	9.10									
		10.20			9.23	8.97							
			13.23	9.95	9.22	9.52							
			11.23	12.76	10.07	9.94	9.70	9.88					
				11.00	10.75	10.46	9.54	9.56	10.14				
					11.39	11.70	10.64	11.06	10.10	10.15			
					14.57	14.68	13.24	11.29	11.33	10.84			
						15.65	14.08	11.94	12.57	12.95	10.87		
							15.53	14.77	16.27	15.92	11.97	10.34	
								15.06	15.21	14.32	12.62	10.82	
								15.70	16.89	15.96	14.18	11.24	

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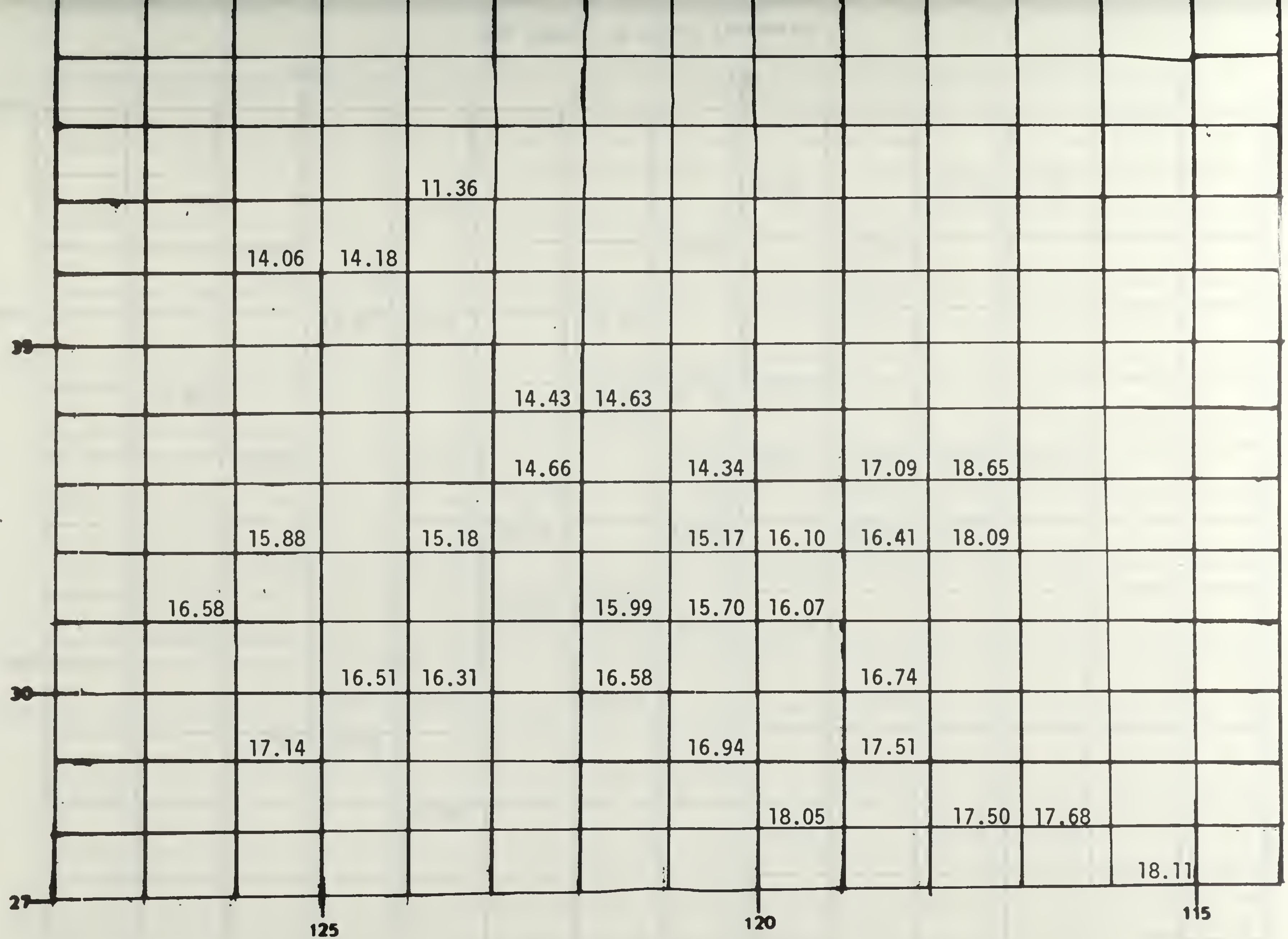
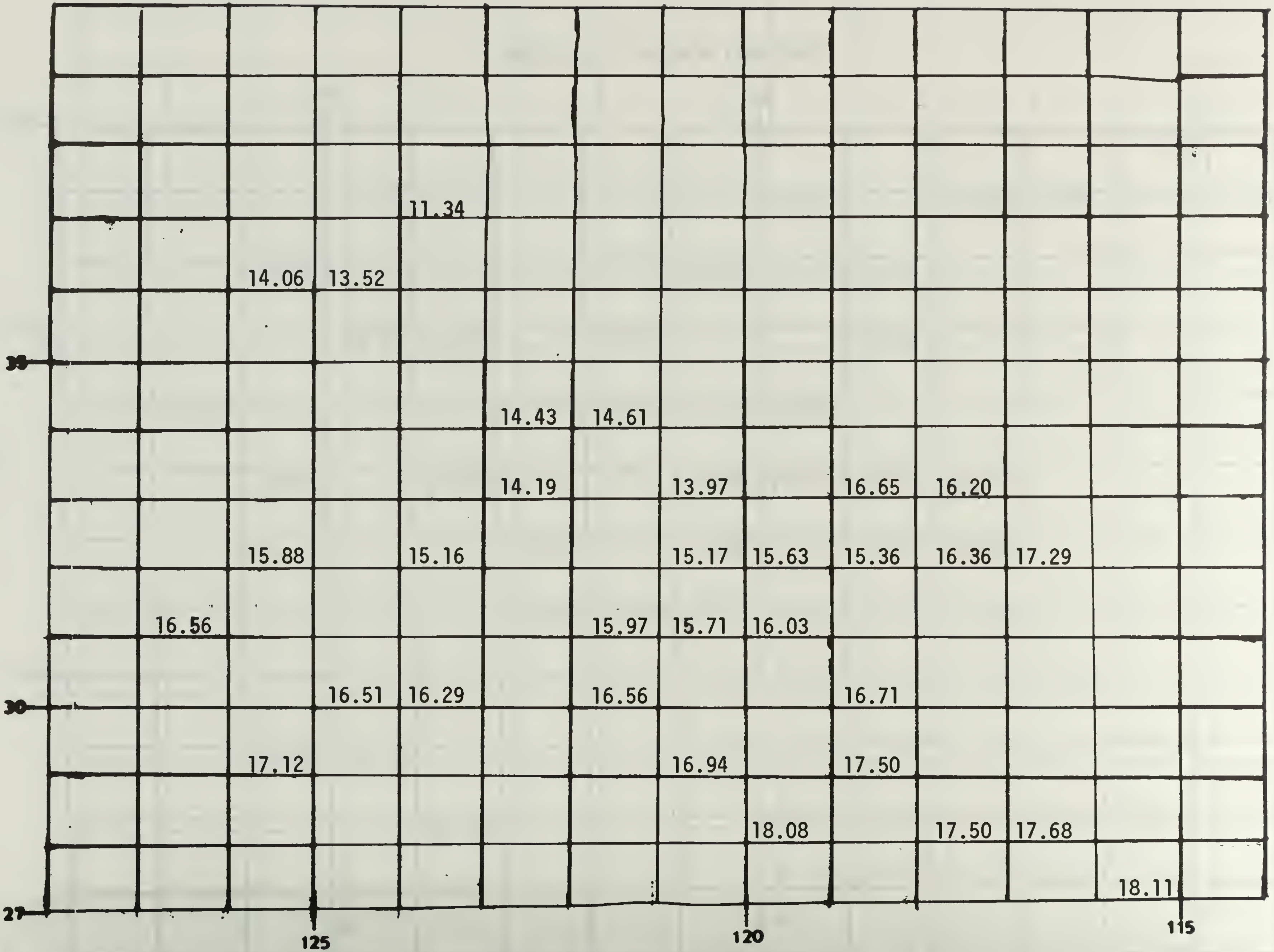
April 1959 - 100 Meter Isotherms



May 1959 - Surface Isotherms



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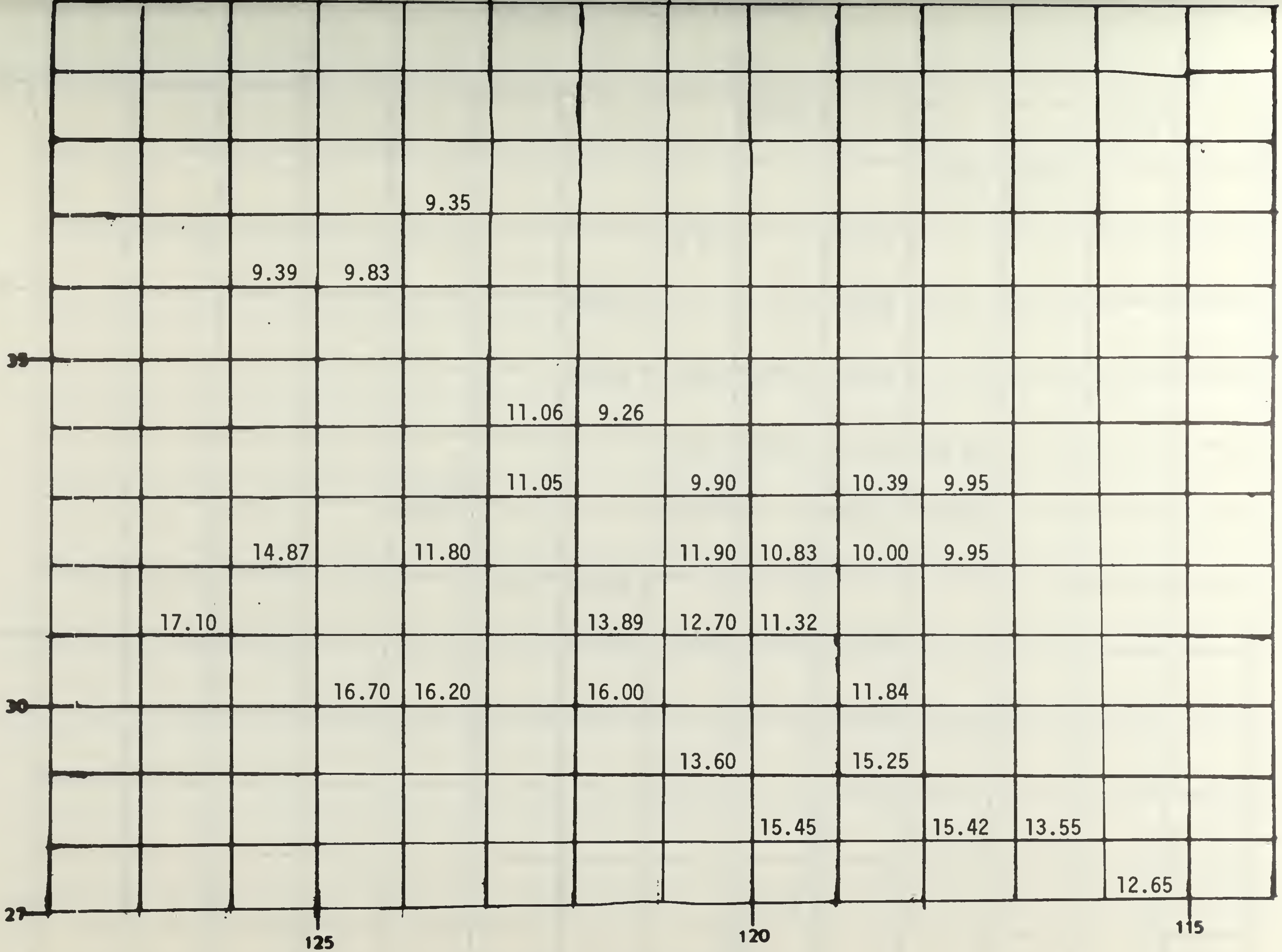
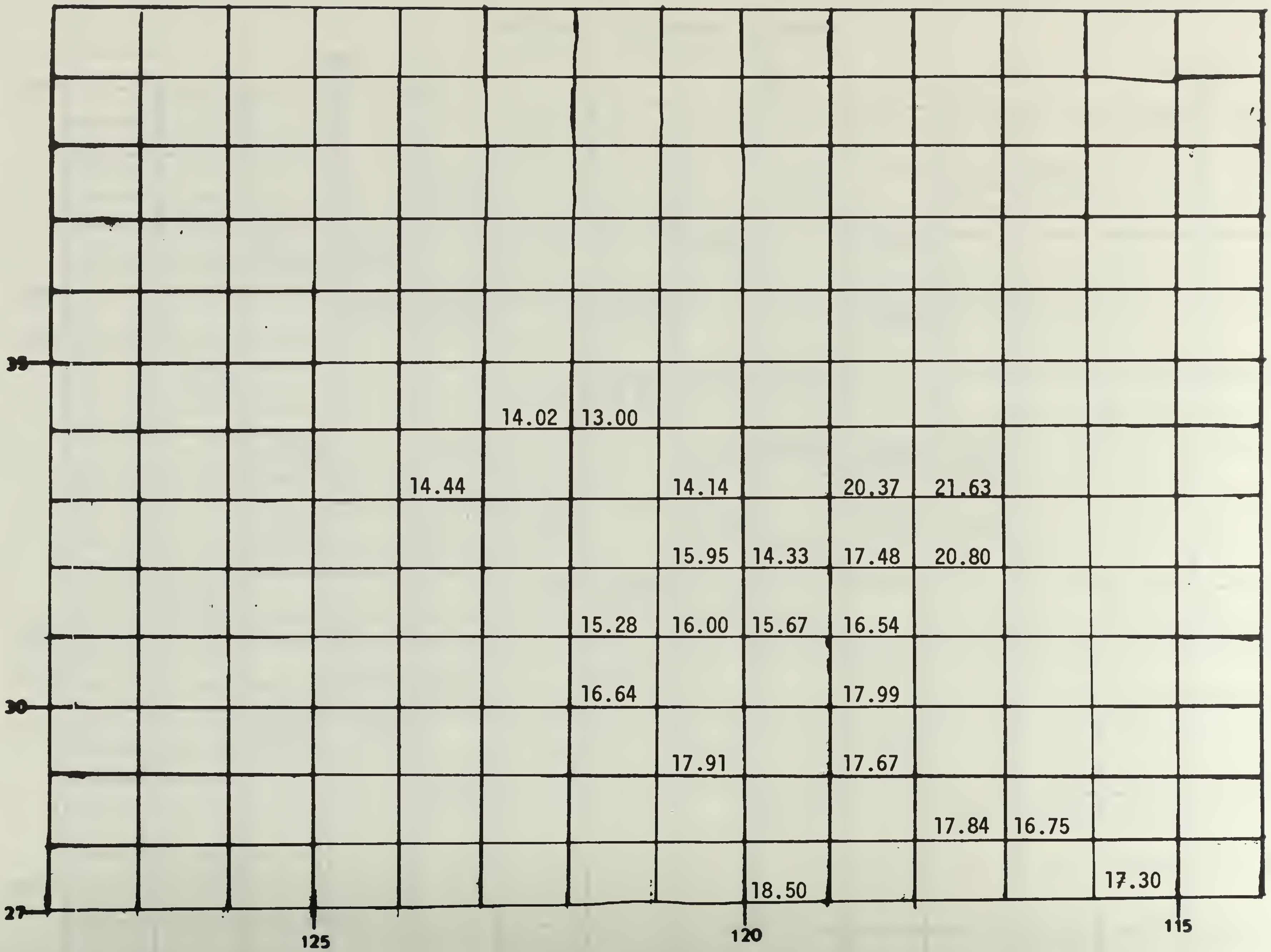
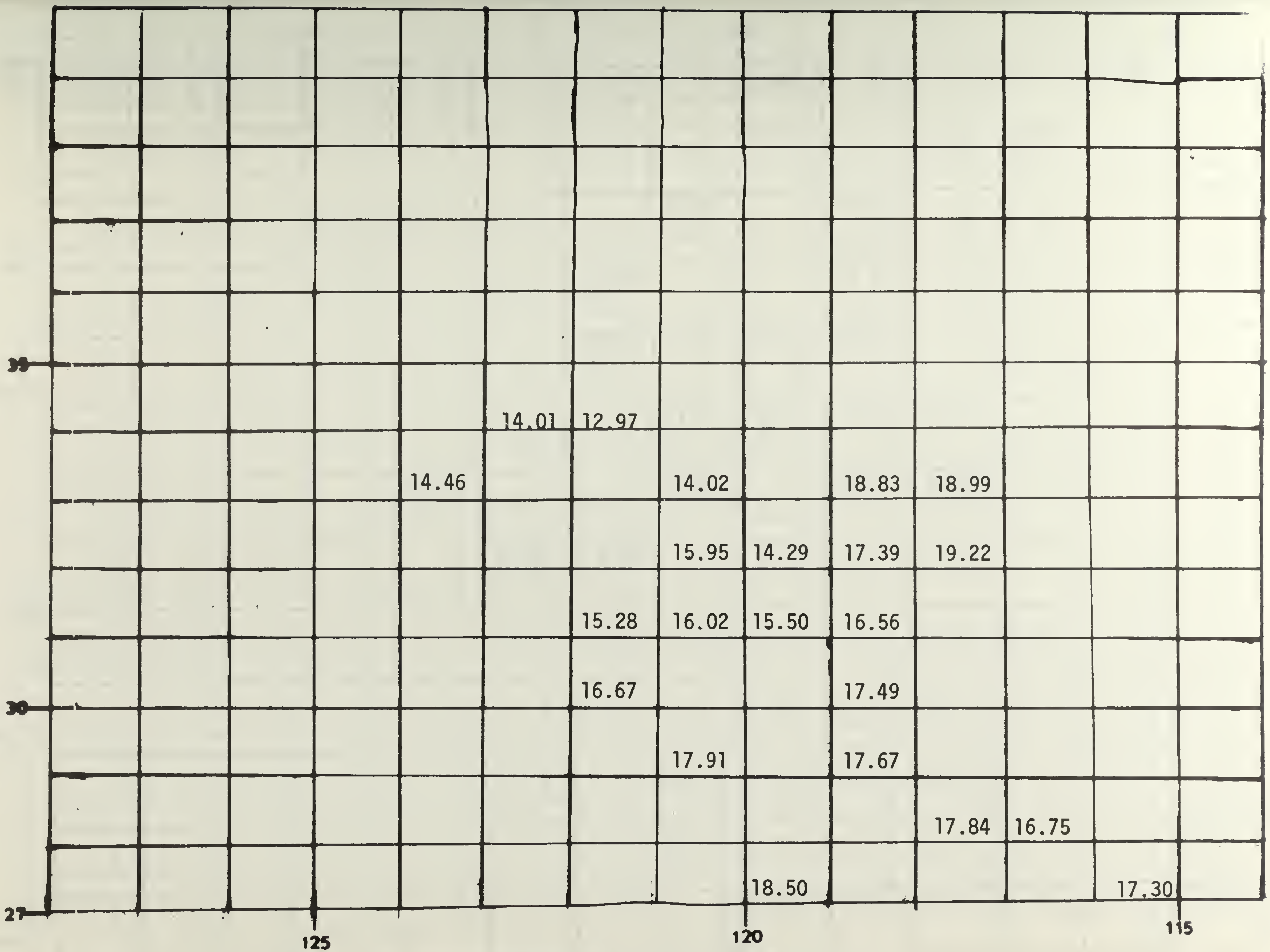


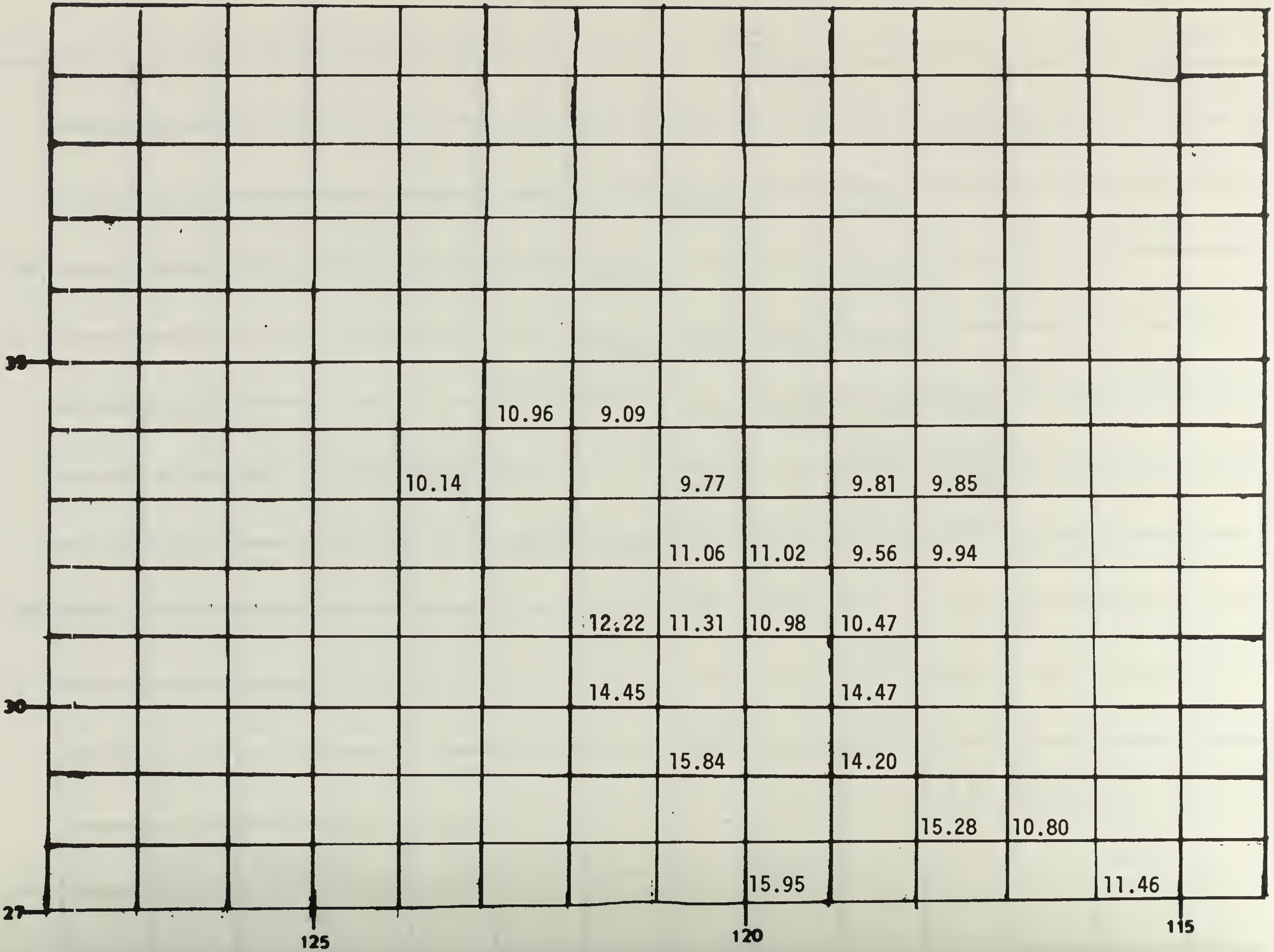
May 1959 - 100 Meter Isotherms



June 1959 - Surface Isotherms



June 1959 - 10 Meter Isotherms



June 1959 - 100 Meter Isotherms

	16.63												
	15.74		14.42	14.29	14.52								
		16.77	17.07	14.78	15.30	14.83							
		16.56	16.40	15.53	14.30	14.08							
			15.64	16.58	15.41	15.73	18.00	20.26					
				16.38	16.90	15.06	18.44	19.21	20.75	21.28			
					17.04	16.32	16.83	17.69	19.02	21.47			
					17.04	17.52	17.78	17.64	20.42	20.62	18.92		
						17.94	17.76	18.03	18.63	20.39	20.37		
							18.62	18.76	21.16	19.35	20.16	19.27	
							19.80	21.25	21.54	20.14	20.74	20.56	20.87
								21.33	21.96	21.34	20.86	21.71	19.57

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July 1959 - Surface Isotherms

	16.66												
	15.71		14.44	14.18									
		16.79	16.71	14.90	14.93	14.84							
		16.47	16.42	15.47	14.30	13.97							
			15.31	16.60	15.15	15.70	16.37	18.55					
				16.39	16.89	15.07	17.21	17.40	20.32	16.35			
					17.02	16.52	16.83	16.59	18.63	17.79			
					17.05	17.41	17.52	17.55	20.42	20.62	14.47		
						17.86	17.76	17.99	18.56	20.25	19.62		
							18.62	18.78	20.93	19.83	18.98		
							19.54	20.91	20.97	20.08	20.54	20.32	20.36
								21.33	21.96	21.38	20.85	21.35	18.97

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July 1959 - 10 Meter Isotherms

	11.78												
	9.66		8.87	8.95									
		11.69	12.62	9.22	8.98	9.51							
		12.72	12.01	9.75	9.52	9.45							
			11.67	12.31	9.34	9.10	9.51	9.71					
				9.60	10.06	9.64	9.82	9.30	10.16	9.98			
					11.12	11.22	11.02	9.38	9.59	10.06			
					12.91	12.57	12.10	9.99	10.66	10.39	10.02		
						14.16	13.96	13.29	12.65	11.29	10.17		
							15.15	14.49	15.69	11.71	11.01	13.01	
							16.00		15.35	14.90	14.23	10.91	
								13.40	16.27	13.19	13.33	10.77	11.40

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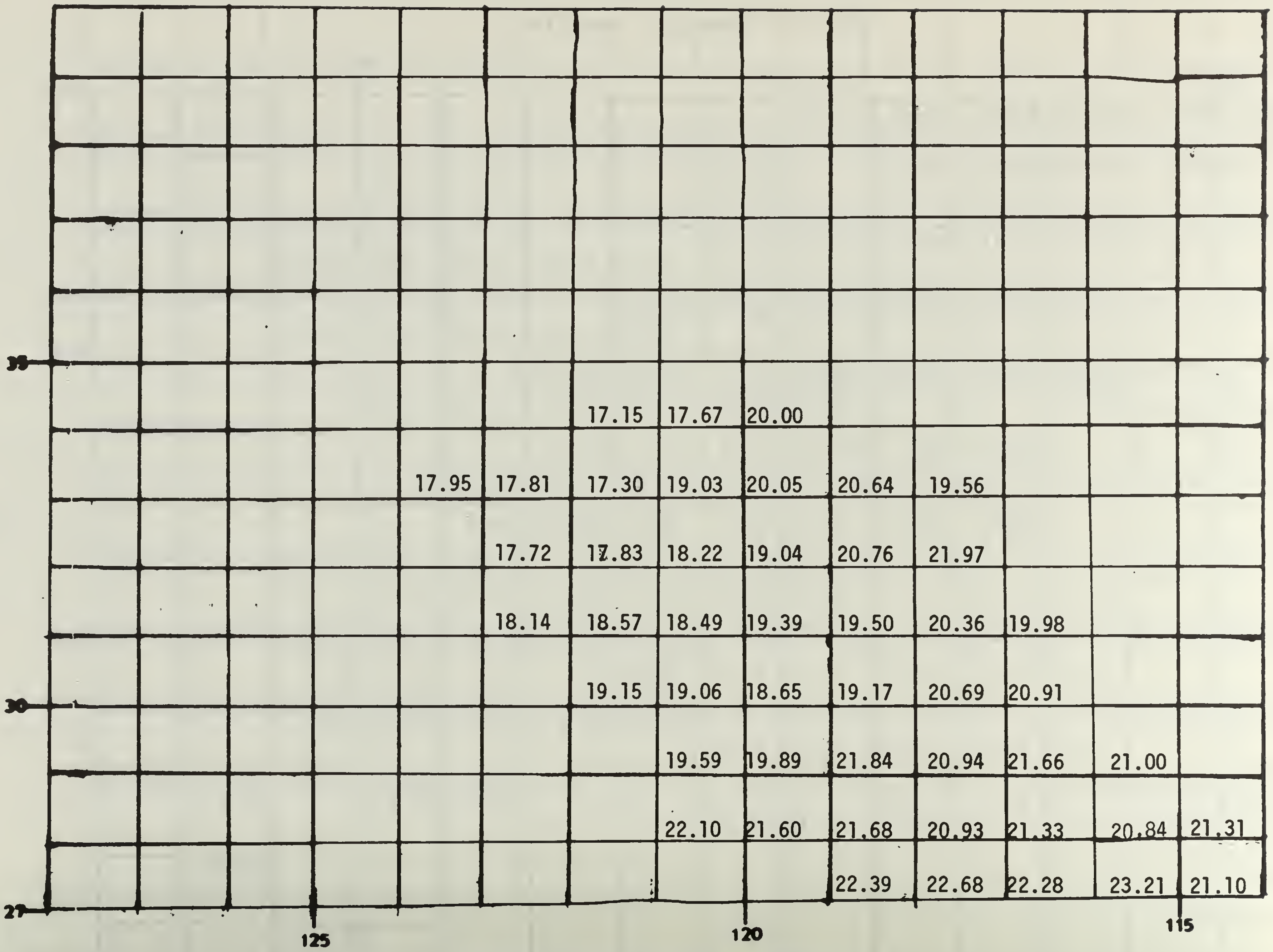
July 1959 - 100 Meter Isotherms



August 1959 - Surface Isotherms

						16.58	16.42	18.53					
				17.96	17.80	17.02	18.46	19.72	20.52	16.56			
					17.63	17.85	19.45	19.01	20.15	20.95			
						18.57	18.49	18.92	19.51	20.34	18.69		
						19.20	19.05	18.66	19.19	20.51	20.52		
							19.59	19.80	21.75	20.89	21.32	20.70	
							22.10	21.59	21.65	20.90	21.28	20.28	20.99
									22.39	22.65	22.18	23.03	21.08

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August 1959 - 10 Meter Isotherms

						9.46	10.52	9.91					
				9.65	10.68	9.25	9.76	10.82	10.46	10.98			
					10.93	11.80	9.51	9.26	10.07	10.79			
					11.73	10.94	11.65	10.14	11.75	11.40	11.45		
						14.28	13.50	12.51	12.79	12.97	11.63		
							16.34	15.27	15.82	16.24	11.42	14.23	
							16.29	16.59		15.60	14.66	12.68	
									13.70	14.31	13.65	11.24	12.31

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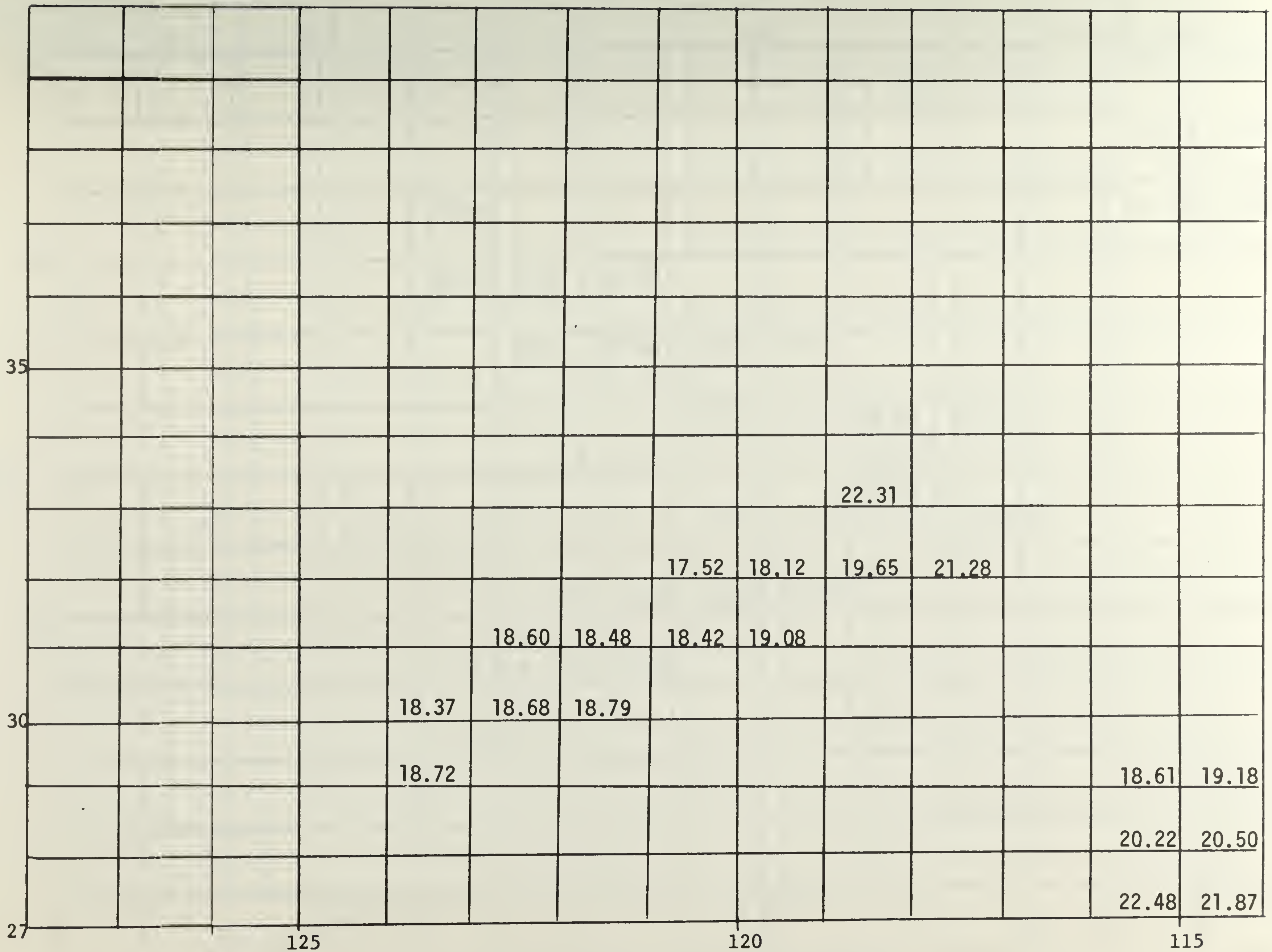
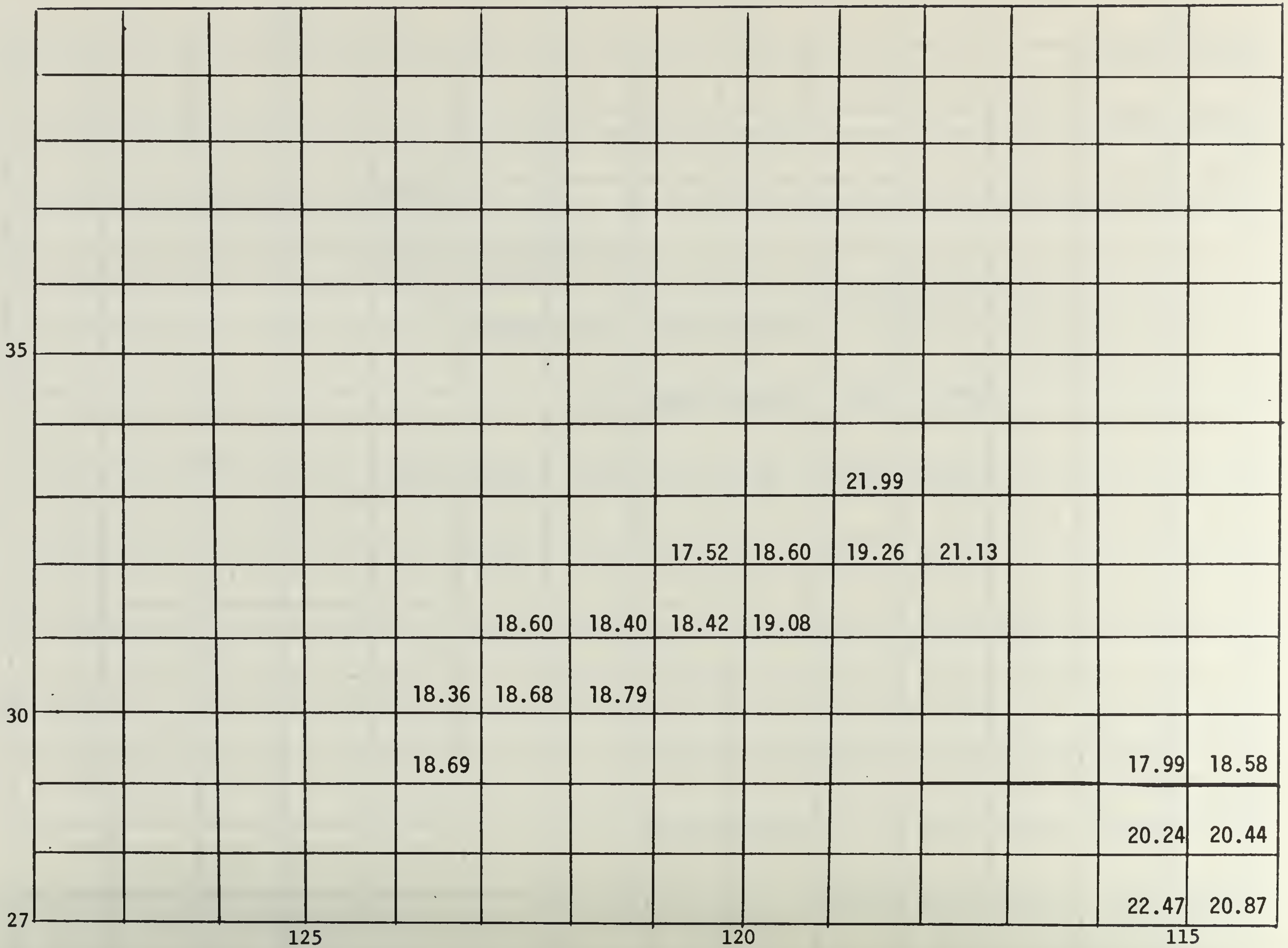
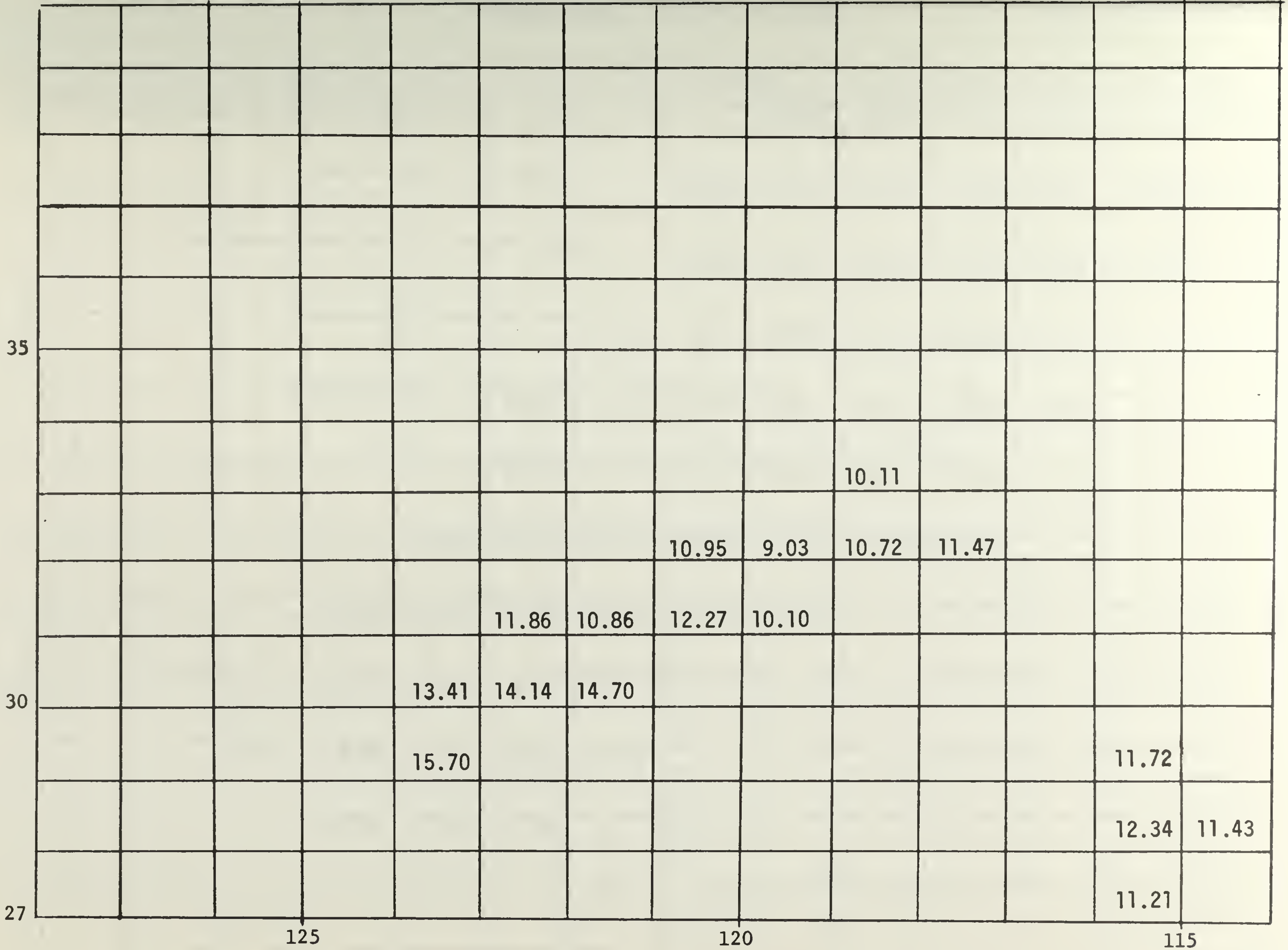
August 1959 - 100 Meter Isotherms



September 1959 - Surface Isotherms



September 1959 - 10 Meter Isotherms



September 1959 - 100 Meter Isotherms

	15.92	14.59	14.02								
16.23	15.96	16.14	15.64	15.80							
	16.43	16.47	16.08	16.57							
	17.06	16.49	17.03	17.20	17.94	19.63					
		17.36	16.43	17.23	18.69	18.82	19.83	20.20			
			16.93	17.40	17.94	18.60	19.03	20.43			
			18.04	17.90	18.46	19.25	20.46	19.78	19.43		
				18.97	18.54	18.55	19.32	20.41	20.14		
					19.66	19.93	19.92	21.22	20.63	17.82	
					20.65	21.02	19.96	20.86	20.33	19.84	20.37
						20.93	20.26	20.23	22.02	21.36	21.62

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125 120 115

October 1959 - Surface Isotherms

17.00	17.35		13.73	12.21									
			15.93	14.59	13.97								
		15.96	15.93	16.11	15.64	15.00							
			16.40	16.48	16.06	16.59							
			17.08	16.46	17.05	17.20	17.94	19.13					
				17.35	16.36	17.14	18.30	18.80	19.76	19.90			
					16.99	17.35	17.94	18.56	18.94	20.27			
					18.03	17.90	18.44	19.18	19.89	19.81	18.61		
						18.98	18.36	18.55	19.32	20.44	20.15		
							19.66	19.79	19.93	21.24	20.61	17.74	
							20.68	21.03	19.97	20.76	20.35	19.78	20.39
								20.95	20.28	20.25	22.03	21.23	21.49

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October 1959 - 10 Meter Isotherms

11.18	11.60		9.23	9.00									
			8.87	9.40									
		10.05	9.31	8.99	10.03	10.90							
			10.85	9.86	9.79	9.46							
			10.50	9.53	9.79	9.79	9.90	10.91					
				12.43	9.72	9.51	9.64	9.12	10.87				
					10.23	9.98	10.36	11.13	10.70	11.23			
					11.73	11.87	11.81	10.66	12.78	12.54	12.14		
						14.67	12.38	11.87	12.60	12.72	11.96		
							13.65	15.75	13.11	11.06	12.10	12.32	
							16.42	16.25	15.32	12.23	13.84	12.30	
								16.30	15.25	14.35	11.13	12.39	11.91

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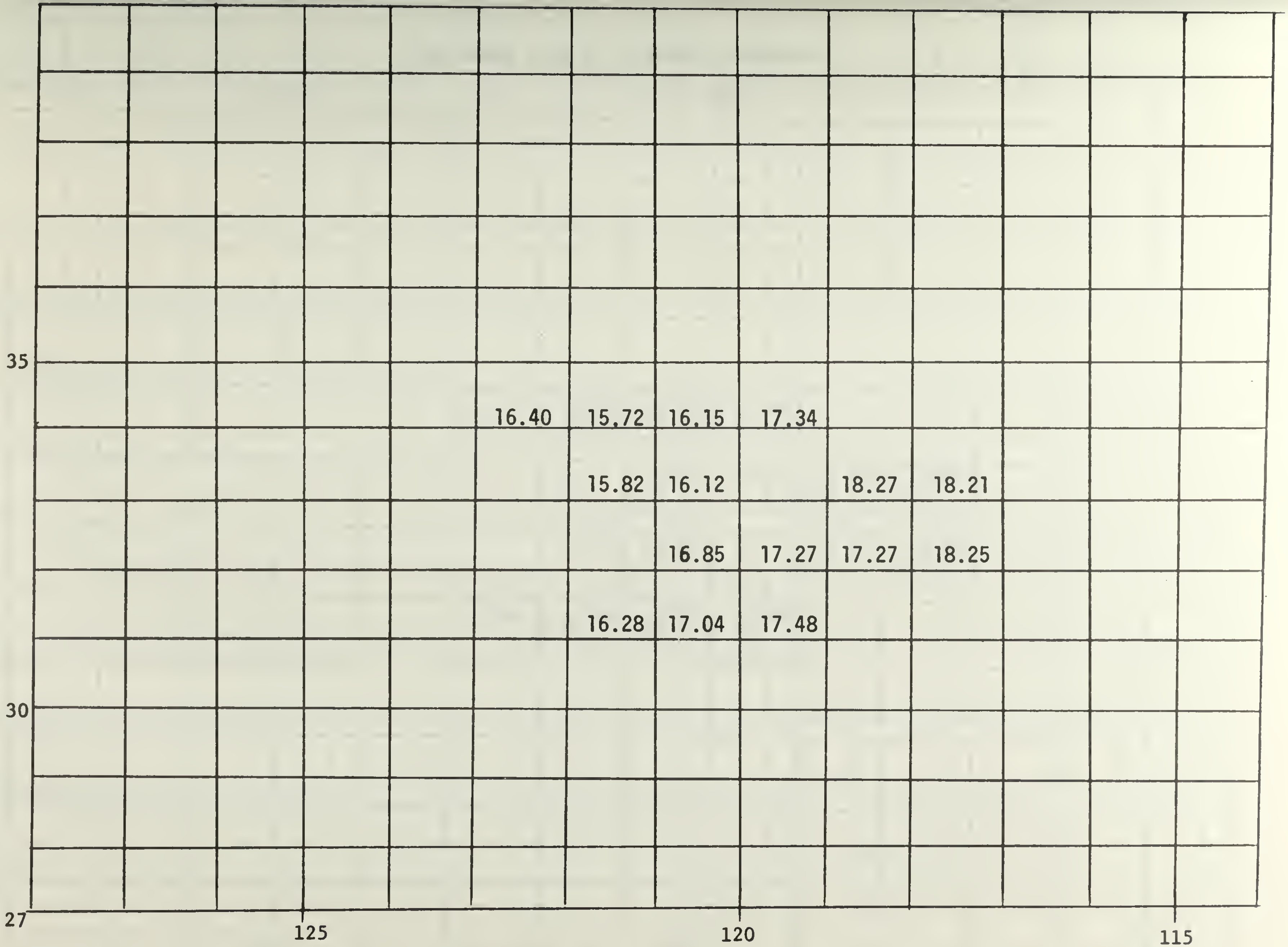
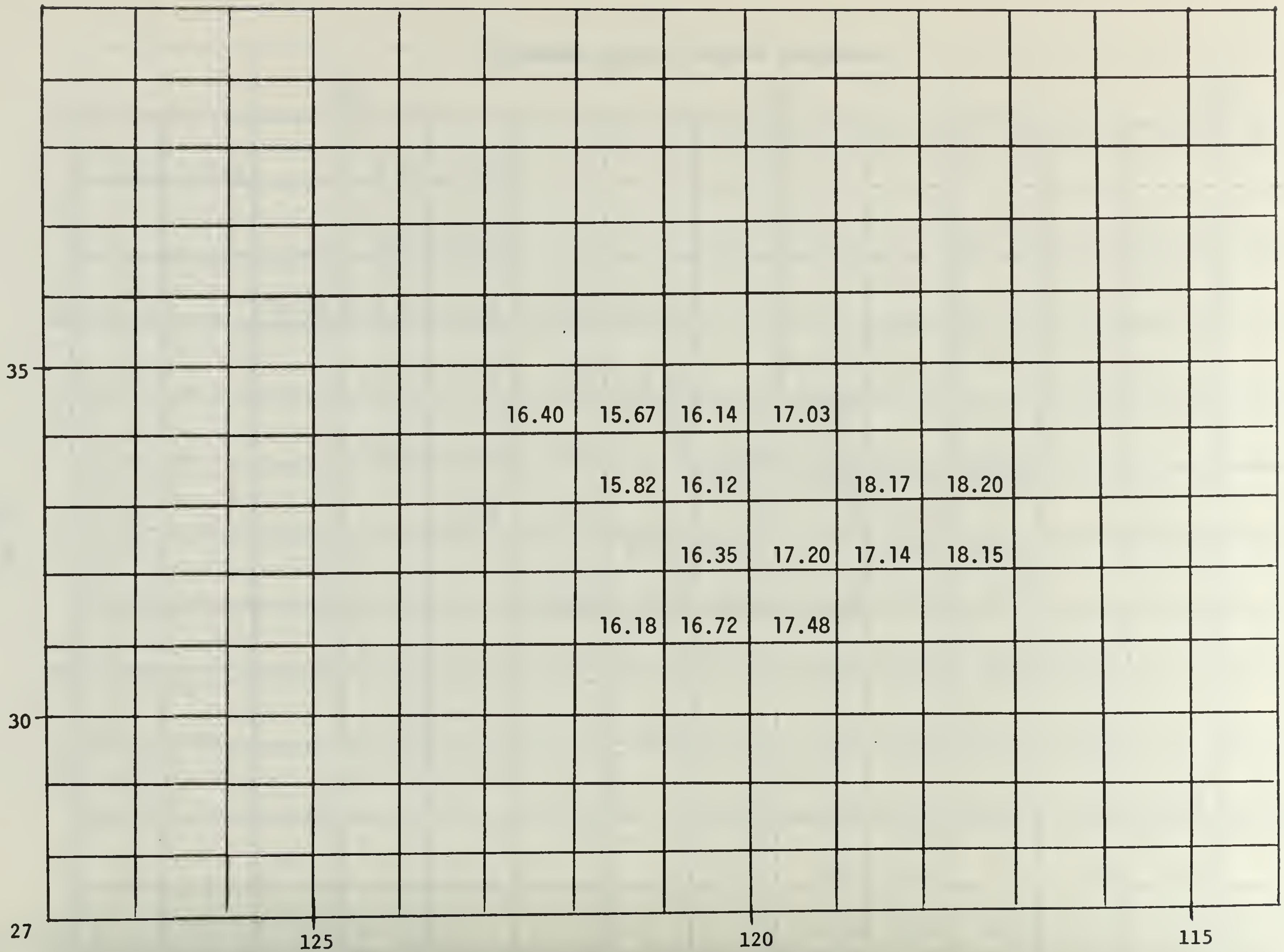
October 1959 - 100 Meter Isotherms



November 1959 - Surface Isotherms



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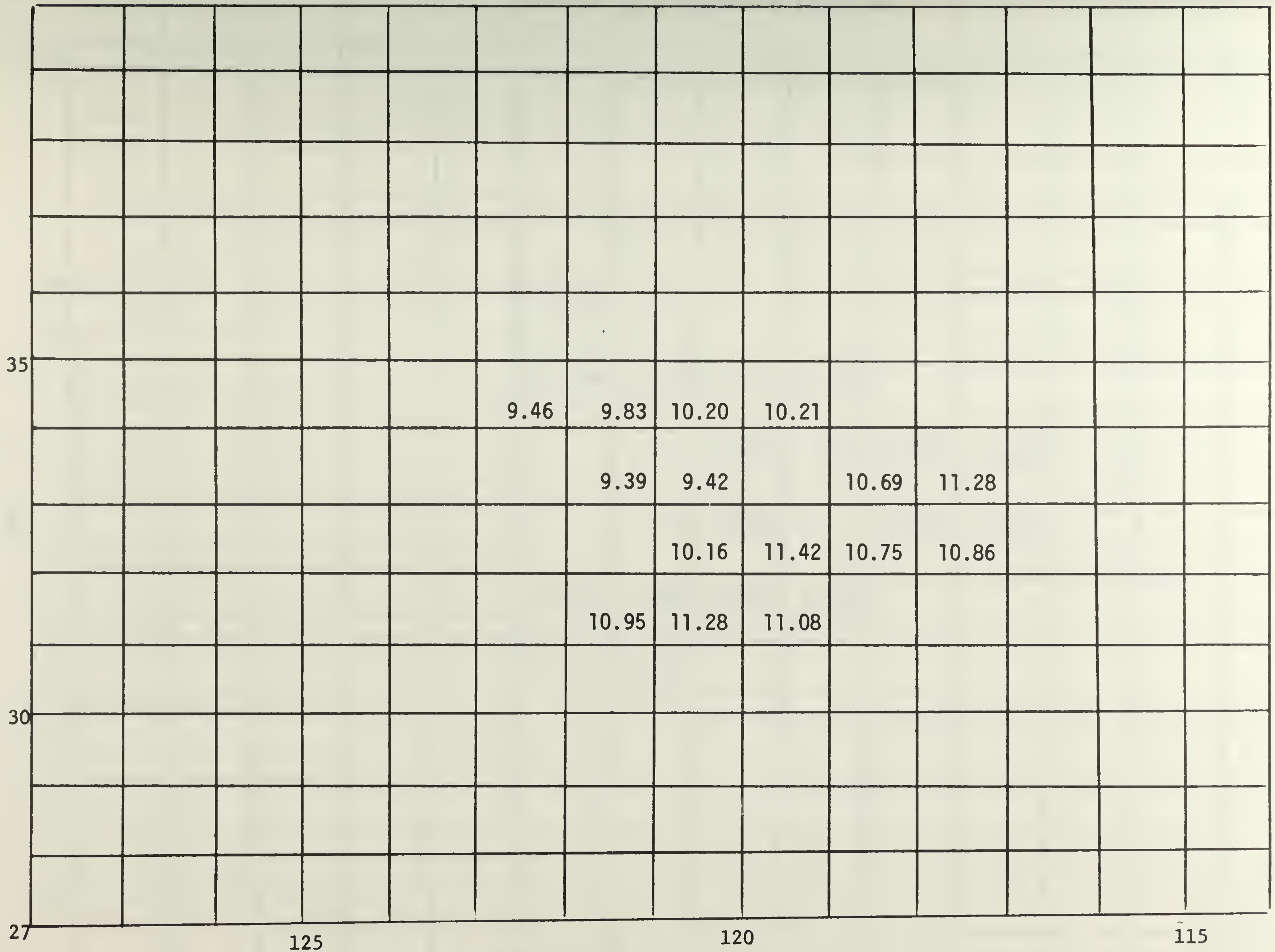

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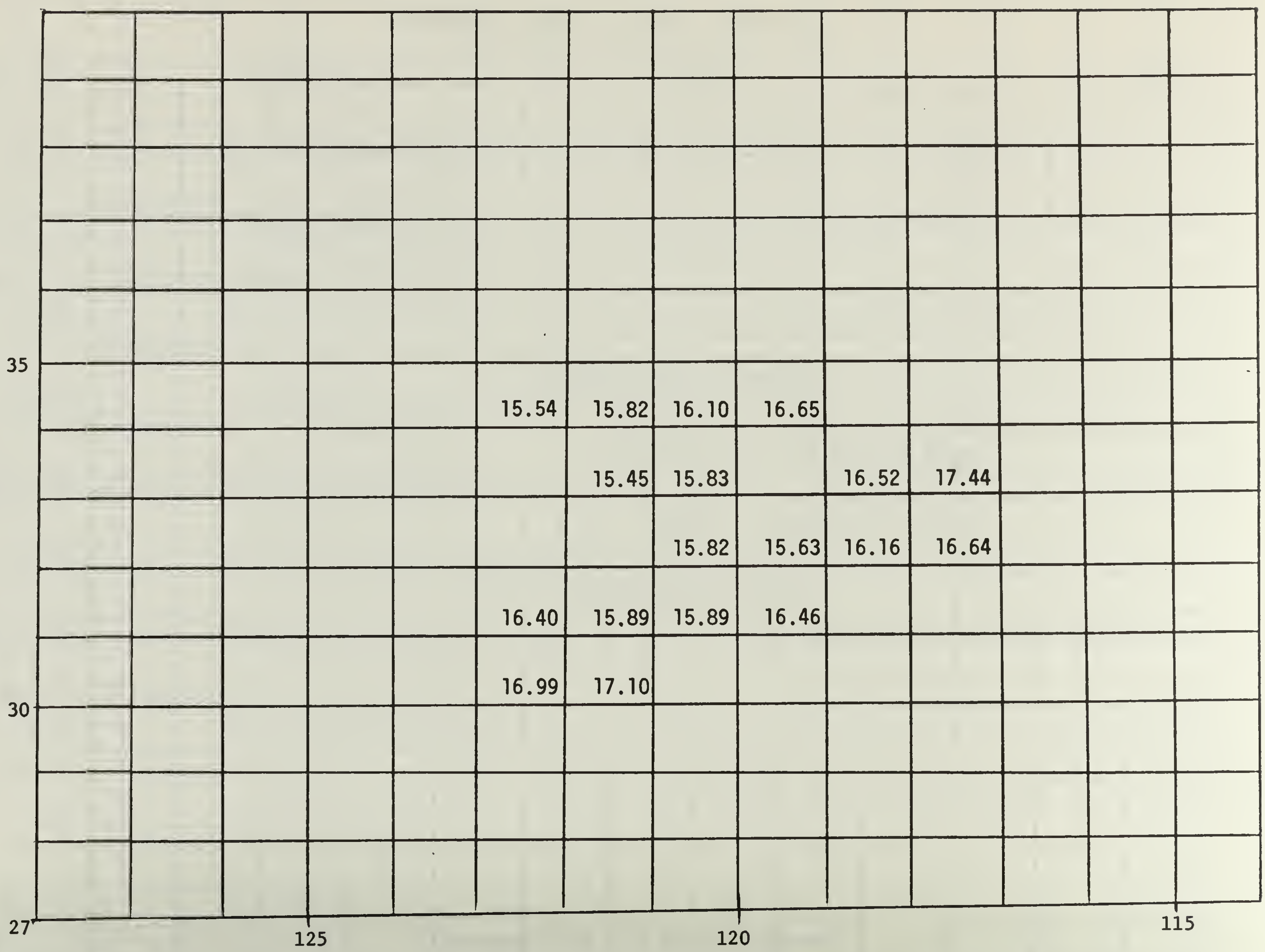
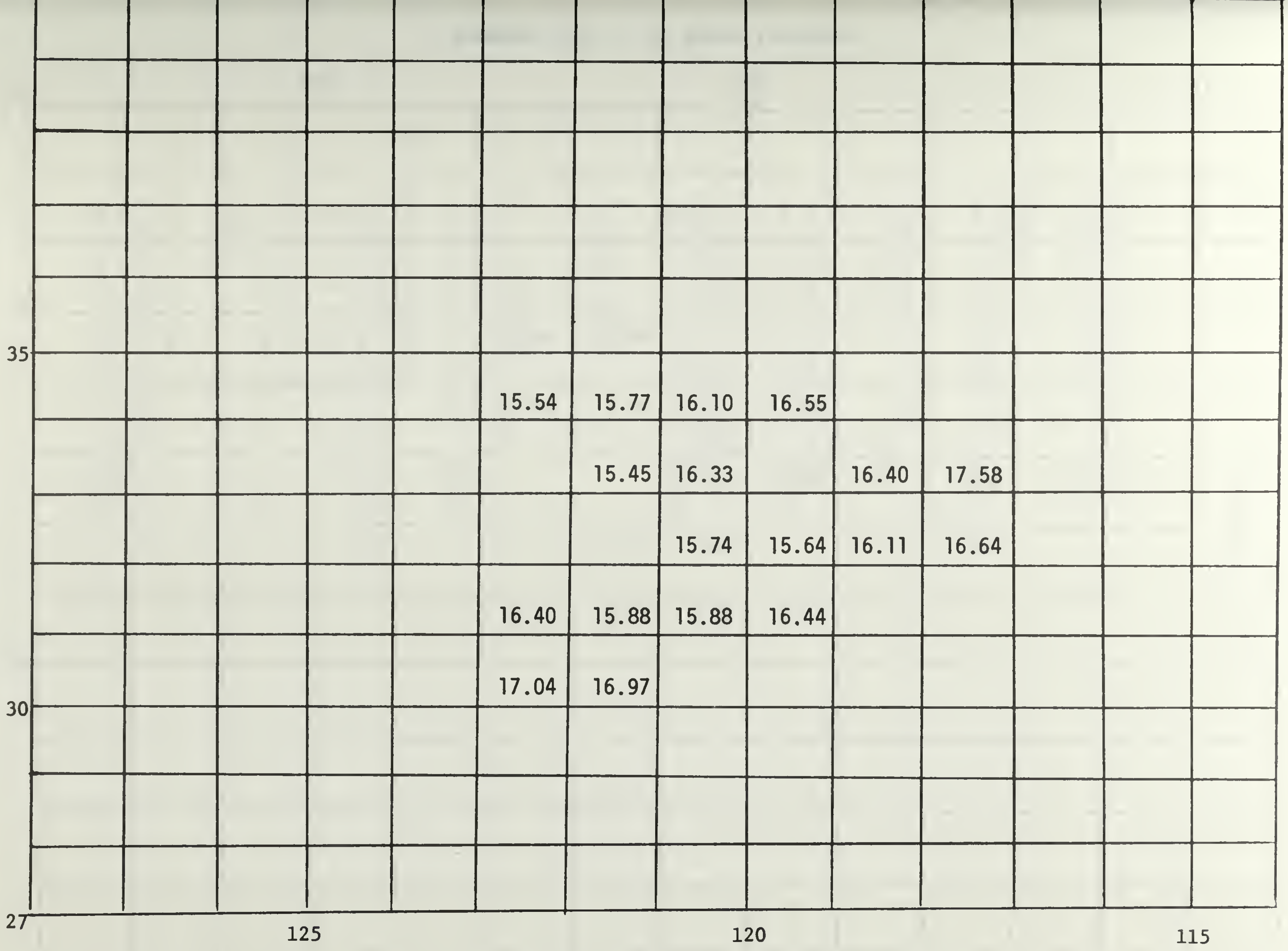
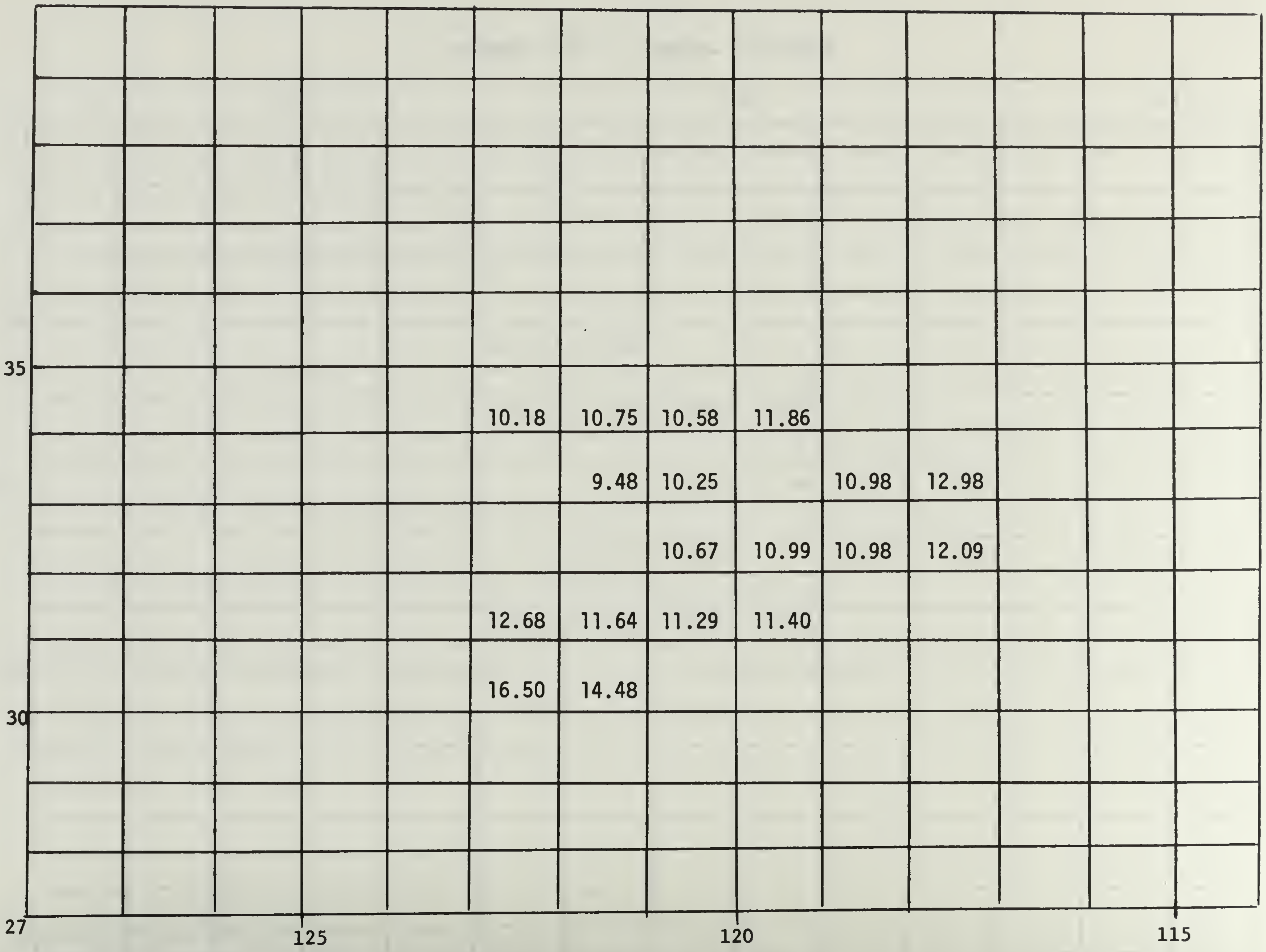


December 1959 - Surface Isotherms



December 1959 - 10 Meter Isotherms



December 1959 - 100 Meter Isotherms

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13. ABSTRACT

A synoptic analysis of the temperature field off the California coast for the surface, 10-meter and 100-meter level is provided for the years 1958-1959. Data used are from CCOFI cruises.

These analyses are shown to be adequate for detecting probable upwelling areas. The areas of persistent upwelling are at 29 N, 31 N and 33 N adjacent to the California coast. There appears to be a preference for a steep gradient of the sea floor in these areas. The onset and decay of upwelling appears to depend on latitudinal position of the 11 C isotherm at 100 meters.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
UPWELLING AREA						
TEMPERATURE FIELD						
DENSITY						
CALIFORNIA COAST						